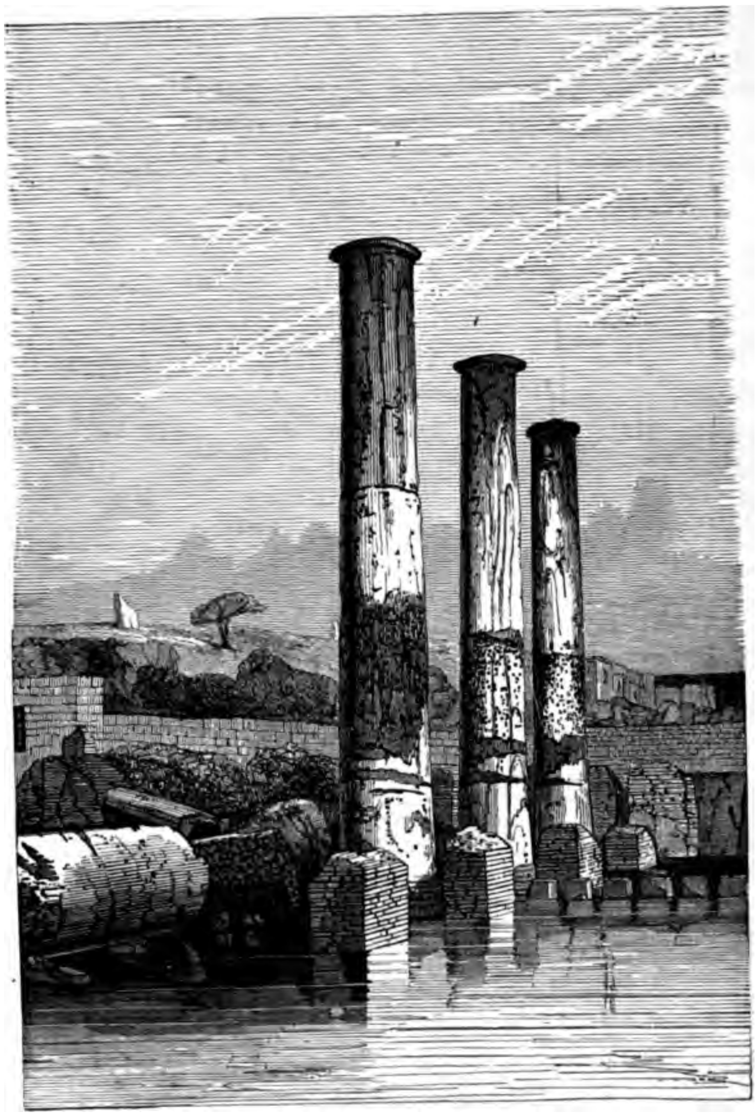
PRINCIPLES

OF

GEOLOGY.

Frontispiece.



VIEW OF THE TEMPLE OF SERAPIS AT PUZZUOLI IN 1836.

See Vol. II. Chap. xxx.

J. C. Branner

PRINCIPLES OF GEOLOGY

OR THE

MODERN CHANGES OF THE EARTH

AND ITS INHABITANTS

CONSIDERED AS ILLUSTRATIVE OF GEOLOGY

BY SIR CHARLES LYELL, BART., M.A., F.R.S.

'Verè scire est per causas scire'—BACON

'The stony rocks are not primeval, but the daughters of Time'—LINNÆUS, *Syst. Nat.* ed. 5, *Stockholm*, 1748, p. 219

'Amid all the revolutions of the globe the economy of Nature has been uniform, and her laws are the only things that have resisted the general movement. The rivers and the rocks, the seas and the continents, have been changed in all their parts; but the laws which direct those changes, and the rules to which they are subject, have remained invariably the same'—PLAYFAIR, *Illustrations of the Huttonian Theory*, § 374

ELEVENTH AND ENTIRELY REVISED EDITION

IN TWO VOLUMES—VOL. I.

Illustrated with Maps, Plates, and Woodcuts

NEW YORK:
D. APPLETON AND COMPANY,
1, 3, AND 5 BOND STREET.
1889.

PREFACE

TO

THE ELEVENTH EDITION.

THERE has been an interval of five years between the last and present edition of this first volume of the 'Principles of Geology.' During this time much discussion has taken place on important theoretical points bearing on meteorology and climate, and much new information obtained by deep-sea dredging in regard to the temperature, and shape, of the bed of the ocean, and its living inhabitants.

In order to avail myself of this newly acquired knowledge, I have found it necessary to recast Chapters X., XI., XII., and XIII., which relate to the geological proofs of former changes of climate, and the paramount importance of the distribution and height of the land over all other causes in bringing about past variations of temperature. At the same time I have endeavoured to render more intelligible some of those astronomical changes which must periodically affect climate, though probably not in so influential a degree as some have imagined.

In Chapter XX. I have briefly dwelt upon the latest known facts concerning marine currents, especially those in the Straits of Gibraltar, and have considered some

theories of oceanic circulation recently propounded to account for the cold of the abysses of the ocean. With these exceptions, the work has been reprinted mainly as it stood in 1867, with corrections and additions.

The changes made in the tenth edition were so numerous and important that I have thought it best to reprint the Preface to that edition in full, thereby giving the reader the opportunity of knowing what advance has been made in the work since 1853 when the ninth edition appeared. The pages of additions and corrections given in that preface correspond so nearly to those of the present volume that the passages referred to may be always found by turning a few pages backwards or forwards.

CHARLES LYELL.

73 Harley Street:
January 16, 1872.

PREFACE

TO

THE TENTH EDITION.

It is now thirteen years and a half since the last or ninth edition of the 'Principles of Geology' appeared; a long interval in the history of the progress of a science, in which so many able investigators and thinkers, in every civilised country of the world, are actively engaged. In re-editing the work, I have found it necessary entirely to re-write some chapters and to recast others, and to modify or omit some passages given in former editions. For the sake of those readers who are already familiar with the 'Principles,' I subjoin a list of the chief additions now made for the first time, pointing out the pages at which corresponding matter occurs in the ninth and tenth editions.

List of the Principal Additions and Corrections in the First Volume of the Tenth Edition of the 'Principles of Geology.'

Ninth Edition.	Tenth Edition.	Additions and Corrections.
Page	Page	
	14	The opinion of Anaximander, 'that fish were the parents of mankind,' how far an anticipation of the modern doctrine of development.
	139	An abridged table of fossiliferous strata in their order of superposition, inserted from the 'Elements' for the sake of reference.
130 to 153	136 to 173	The Ninth Chapter, on the progressive development of organic life, has been entirely re-written.

Ninth Edition.	Tenth Edition.	Additions and Corrections.
Page 73 to 91	Page 174 to 211	The Tenth Chapter (corresponding in part with Chapter VI. of the former edition) has also been re-written. It treats of the changes of climate, established on evidence, organic and inorganic, derived from the Tertiary and Post-tertiary formations.
92 to 113	212 to 232	The Eleventh Chapter is new, treating of the proofs of former vicissitudes in climate, derived from the study of the Secondary and Primary fossiliferous formations.
113 to 130	233 to 267	The Twelfth Chapter, on the geographical causes of former changes in climate, has been re-written. It is illustrated by three new maps.
100 and 126	268 to 304	In the Thirteenth Chapter, to which there are only a few passages corresponding in former editions, I have considered how far former vicissitudes in climate may have been influenced by astronomical changes; such as variations in the excentricity of the earth's orbit, changes in the obliquity of the ecliptic, and different phases of the precession of the equinoxes. Mr. Croll's suggestion as to the probable effects of a large excentricity in producing glacial epochs is fully discussed, and the question is entertained whether geological dates may be obtained, by reference to the combined effect of astronomical and geographical causes.
204	335	The earth-pillars or pyramids of Botzen in the Tyrol and other localities, illustrated by a drawing of Sir John Herschel's, are here introduced, as showing the power of rain as distinct from that of running water. The glacial origin of the formation of which the pillars are made is also pointed out.
223	372	Notice of the theory of regelation of Tyndall and Faraday in explanation of the motion of glaciers.
	376	The glacier-lake of the Alps called 'the Märjelen See,' described and illustrated by two diagrams, and its bearing on the origin of the parallel roads of Glenroy explained.
	393	Live fish rising in the Artesian wells of the Sahara.
237	398	Facts relating to the origin of mineral and thermal waters and the hot springs of Bath.
	420	Playfair on the origin of the lake-basin of Geneva.
	434	Mr. Horner on the mode of computing the antiquity of the Nile mud; with the opinions of Mr. S. Sharpe, Sir J. Lubbock, and Mr. Wallace on the subject.
	447	A new hypothesis proposed to explain the origin of the 'mud-lumps' of the mouths of the Mississippi, illustrated by a map and two views.
271	457	The antiquity of the delta and alluvial plain of the Mississippi discussed with reference to new facts brought to light during the survey of Messrs. Humphreys and Abbot, in 1861, and the boring of the Artesian well at New Orleans in 1854, to the depth of 600 feet.
	461	Mr. H. W. Bates and Professor Agassiz on the delta of the Amazons.
		Freshwater deposits supposed by Agassiz to indicate an ancient lake closed by a terminal moraine of a glacier considered.
279	475	Delta of the Ganges—Mr. Fergusson's opinions as to the

Ninth Edition.	Tenth Edition.	Additions and Corrections.
Page	Page	origin of 'the swatch' and the mode of formation of the elevated banks of rivers.
291	495	Various causes of currents treated of more fully than in the former edition.
306	514	Waste of the coast of Norfolk illustrated by the ruins of Eccles Church as they appeared in 1839 and in 1862. A drawing by the Rev. S. W. King of the church in 1862.
323	539	St. Michael's Mount, Cornwall—Three views of the Mount Its identity with the Ictis of Diodorus—Drawing of a block of tin dredged up in Falmouth Harbour.
334	563	Temperature of different divisions or basins of the Mediterranean compared to that of the Atlantic—Saltness of the Mediterranean, and a diagram illustrating the result of Captain Spratt's survey.
340	568	Shoals and valleys in the German Ocean—The Silver Pits and Dogger Bank—Comparison of the recent deposits of these shoals and the crag of Norfolk and Suffolk.
	616	Internal talus of Monte Nuovo, containing fragments of marine shells and pottery, with a section of the mountain.
	625	Ropy lava and origin of this structure.
	633	Hypothesis of elevation craters not applicable to Somma or Vesuvius—Ravines on the north side of Somma, and the light which they throw on its structure, from observations made by the author in 1857 and 1858—Presence of land-plants and absence of contemporaneous marine shells in the ancient tuffs of Monte Somma.

The reader may also be interested in knowing the dates of the successive editions of this treatise, as well as of two other of my geological works, which are intimately connected with it.

List of the dates of publication of successive Editions of the 'Principles,' 'Elements,' and the 'Antiquity of Man.'

Principles, vol. i. in 8vo., published in	Jan. 1830.
——— „ ii. „	Jan. 1832.
——— „ i. 2nd edition in 8vo.	1832.
——— „ ii. 2nd edition „	Jan. 1833.
——— „ iii. 1st edition „	May 1833.
——— New edition (called the 3rd) of the whole work in 4 vols. 12mo.	May 1834.
——— 4th edition, 4 vols. 12mo	June 1835.
——— 5th „ „ „	Mar. 1837.
Elements, 1st edition in 1 vol.	July 1838.
Principles, 6th „ 3 vols. 12mo.	June 1840.
Elements, 2nd edition in 2 vols. 12mo.	July 1841.

Principles, 7th edition, in 1 vol. 8vo. published in . . .	Feb. 1847.
——— 8th edition „ „	May 1850.
Elements, 3rd edition (or Manual of Elementary Geology) in 1 vol. 8vo.	Jan. 1851.
Elements, 4th edition (or Manual) in 1 vol. 8vo. . . .	Jan. 1852.
Principles, 9th edition, published in 1 vol. 8vo. . . .	June 1853.
Elements, 5th edition, in 1 vol.	1855.
Antiquity of Man, 1st, 2nd, and 3rd editions .	Feb.—Nov. 1863.
Elements, 6th edition, in 1 vol. 8vo.	Jan. 1865.
Principles, 10th edition, in 2 vols. 8vo., the first now published.	Nov. 1866.

⁂ Dec. 1871.—Since the above list was made the second volume of the 'Principles' was published in 1868, and the 'Student's Elements of Geology' in Jan. 1871.

The 'Principles of Geology,' in the first five editions, embraced not only a view of the *modern changes* of the earth and its inhabitants, but also some account of those monuments and analogous changes of *ancient* date, both in the organic and inorganic world, which the geologist is called upon to interpret. The subject last mentioned, or geology proper, constituted originally a fourth book, now omitted, the same having been enlarged into a separate treatise, first published in 1838, in one volume 12mo., and called 'The Elements of Geology,' afterwards recast in two volumes 12mo. in 1842, again re-edited under the title of 'Manual of Elementary Geology,' in one volume 8vo. in 1851, and lastly under the title of 'Elements of Geology,' in one volume 8vo. in 1865.

The 'Principles' and 'Elements,' thus divided, occupy, with one exception, to which I shall presently allude, very different ground. The 'Principles' treat of such portions of the economy of existing nature, animate and inanimate, as are illustrative of Geology, so as to comprise an investigation of the permanent effects of causes now in action, which may serve as records to after ages of the present condition of the globe and its inhabitants. Such effects are the enduring monuments of the ever-varying state of the physical geography of the globe, the lasting signs of its partial destruction and renovation, and the memorials of the equally fluctuating condition of the organic world. They may be

regarded, in short, as a symbolical language, in which the earth's autobiography is written.

In the 'Elements of Geology,' on the other hand, I have treated briefly of the component materials of the earth's crust, their arrangement and relative position, and their organic contents, which, when deciphered by aid of the key supplied by the study of the modern changes above alluded to, reveal to us the annals of a grand succession of past events—a series of revolutions which the solid exterior of the globe, and its living inhabitants, have experienced in times almost entirely antecedent to the advent of man.

In thus separating the two works, however, I have retained in the 'Principles' (Book I.) the discussion of some matters which might fairly be regarded as common to both treatises; as for example, an historical sketch of the early progress of geology, followed by a series of preliminary essays to explain the facts and arguments which lead me to believe that the forces now operating upon and beneath the earth's surface may be the same, both in kind and degree, as those which at remote epochs have worked out geological changes.

If I am asked whether the 'Principles' or the 'Elements' should be studied first, I feel much the same difficulty in answering the question as if a student should enquire whether he ought to take up first a treatise on Chemistry, or one on Natural Philosophy, subjects sufficiently distinct, yet inseparably connected. On the whole, while I have endeavoured to make the two treatises, in their present form, each quite independent of the other, I would recommend the reader to study first the modern changes of the earth and its inhabitants as they are discussed in the present volume, proceeding afterwards to the classification and interpretation of the monuments of more remote ages.

It will be seen in the foregoing list of the dates of publication, that in 1863 I brought out a volume on 'the Antiquity of Man,' or to state the title more fully, 'On the

Geological Evidences of the Antiquity of Man, with Remarks on Theories of the Origin of Species by Variation.'

The subject-matter of this work coincided in part with that treated of in the 'Principles' and 'Elements,' namely, the fossil remains of Man and his works; but whereas these topics occupy a few pages only in the 'Elements' and 'Principles,' half a volume is devoted to them in the 'Antiquity of Man.' In the latter treatise also, the account given of the Glacial Period, and its relation to the earliest signs of Man's appearance in Europe and North America, is much more expanded than in the 'Elements' and 'Principles,' and regarded from a different point of view. The manner also in which the origin of species is handled in the 'Antiquity of Man' will be found to be different in many respects from that in which I shall view the same subject in the concluding volume of this work.

CHARLES LYELL.

73 Harley Street:
November 6, 1866.

CONTENTS

OF

THE FIRST VOLUME.

BOOK I.

CHAPTER I.

INTRODUCTORY.

CHAPTER II.

HISTORY OF THE PROGRESS OF GEOLOGY.

CHAPTER III.

HISTORY OF THE PROGRESS OF GEOLOGY—*continued.*

CHAPTER IV.

HISTORY OF THE PROGRESS OF GEOLOGY—*continued.*

CHAPTER V.

PREJUDICES WHICH HAVE RETARDED THE PROGRESS OF GEOLOGY.

CHAPTER VI.

SUPPOSED INTENSITY OF AQUEOUS CAUSES AT REMOTE PERIODS.

CHAPTER VII.

OF THE SUPPOSED FORMER INTENSITY OF THE IGNEOUS FORCES.

CHAPTER VIII.

DIFFERENCE IN TEXTURE OF THE OLDER AND NEWER ROCKS.

CHAPTER IX.

THEORY OF THE PROGRESSIVE DEVELOPMENT OF ORGANIC LIFE AT SUCCESSIVE GEOLOGICAL PERIODS.

CHAPTER X.

FURTHER CONSIDERATION OF THE AGREEMENT OF THE ANCIENT AND MODERN CAUSES OF CHANGE—VICISSITUDES IN CLIMATE.

CHAPTER XI.

FORMER VICISSITUDES IN CLIMATE—*continued.*

CHAPTER XII.

VICISSITUDES IN CLIMATE CAUSED BY GEOGRAPHICAL CHANGES.

CHAPTER XIII.

VICISSITUDES IN CLIMATE HOW FAR INFLUENCED BY ASTRONOMICAL CHANGES.

CHAPTER XIV.

UNIFORMITY IN THE SERIES OF PAST CHANGES IN THE ANIMATE AND INANIMATE WORLD.

BOOK II.

CHANGES NOW IN PROGRESS IN THE INORGANIC WORLD.

CHAPTER XV.

AQUEOUS CAUSES.

CHAPTER XVI.

TRANSPORTATION OF SOLID MATTER BY ICE.

CHAPTER XVII.

PHENOMENA OF SPRINGS.

CHAPTER XVIII.

REPRODUCTIVE EFFECTS OF RIVERS.

CHAPTER XIX.

REPRODUCTIVE EFFECTS OF RIVERS—*continued.*

CHAPTER XX.

DESTROYING AND TRANSPORTING EFFECTS OF TIDES AND CURRENTS.

CHAPTER XXI.

ACTION OF TIDES AND CURRENTS—*continued.*

CHAPTER XXII.

REPRODUCTIVE EFFECTS OF TIDES AND CURRENTS.

CHAPTER XXIII.

IGNEOUS CAUSES.

CHAPTER XXIV.

VOLCANIC DISTRICT OF NAPLES.

CHAPTER XXV.

VOLCANIC DISTRICT OF NAPLES—*continued.*

LIST OF PLATES.

Directions to the Binder.

PRINCIPLES

OF

GEOLOGY.

CHAPTER I.

GEOLOGY DEFINED—COMPARED TO HISTORY—ITS RELATION TO OTHER PHYSICAL SCIENCES—NOT TO BE CONFOUNDED WITH COSMOGONY.

GEOLOGY is the science which investigates the successive changes that have taken place in the organic and inorganic kingdoms of nature; it enquires into the causes of these changes, and the influence which they have exerted in modifying the surface and external structure of our planet.

By these researches into the state of the earth and its inhabitants at former periods, we acquire a more perfect knowledge of its present condition, and more comprehensive views concerning the laws now governing its animate and inanimate productions. When we study history, we obtain a more profound insight into human nature, by instituting a comparison between the present and former states of society. We trace the long series of events which have gradually led to the actual posture of affairs; and by connecting effects with their causes, we are enabled to classify and retain in the memory a multitude of complicated relations—the various peculiarities of national character—the different degrees of moral and intellectual refinement, and numerous other circumstances, which, without historical associations, would be uninteresting or imperfectly understood. As the

present condition of nations is the result of many antecedent changes, some extremely remote, and others recent, some gradual, others sudden and violent; so the state of the natural world is the result of a long succession of events; and if we would enlarge our experience of the present economy of nature, we must investigate the effects of her operations in former epochs.

We often discover with surprise, on looking back into the chronicles of nations, how the fortune of some battle has influenced the fate of millions of our contemporaries, when it has long been forgotten by the mass of the population. With this remote event we may find inseparably connected the geographical boundaries of a great state, the language now spoken by the inhabitants, their peculiar manners, laws, and religious opinions. But far more astonishing and unexpected are the connections brought to light, when we carry back our researches into the history of nature. The form of a coast, the configuration of the interior of a country, the existence and extent of lakes, valleys, and mountains, can often be traced to the former prevalence of earthquakes and volcanos in regions which have long been undisturbed. To these remote convulsions the present fertility of some districts, the sterile character of others, the elevation of land above the sea, the climate, and various peculiarities, may be distinctly referred. On the other hand, many distinguishing features of the surface may often be ascribed to the operation, at a remote era, of slow and tranquil causes—to the gradual deposition of sediment in the lake or in the ocean, or to the prolific increase of testacea and corals.

To select another example: we find in certain localities subterranean deposits of coal, consisting of vegetable matter, which formerly grew like peat, in swamps, or was drifted into seas and lakes. These seas and lakes have since been filled up, the lands whereon the forests grew have been submerged and covered with new strata, the rivers and currents which floated the vegetable masses can no longer be traced, and the plants belong to species which for ages have passed away from the surface of our planet. Yet the commercial prosperity, and numerical strength of a nation, may now be

mainly dependent on the local distribution of fuel determined by that ancient state of things.

Geology is intimately related to almost all the physical sciences, as history is to the moral. An historian should, if possible, be at once profoundly acquainted with ethics, politics, jurisprudence, the military art, theology; in a word, with all branches of knowledge by which any insight into human affairs, or into the moral and intellectual nature of man, can be obtained. It would be no less desirable that a geologist should be well versed in chemistry, natural philosophy, mineralogy, zoology, comparative anatomy, botany; in short, in every science relating to organic or inorganic nature. With these accomplishments, the historian and geologist would rarely fail to draw correct and philosophical conclusions from the various monuments transmitted to them of former occurrences. They would know to what combination of causes analogous effects were referable, and they would often be enabled to supply, by inference, information concerning many events unrecorded in the defective archives of former ages. But as such extensive acquisitions are scarcely within the reach of any one individual, it is necessary that men who have devoted their lives to different departments should unite their efforts; and as the historian receives assistance from the antiquary, and from those who have cultivated different branches of moral and political science, so the geologist should avail himself of the aid of many naturalists, and particularly of those who have studied the fossil remains of lost species of animals and plants.

The analogy, however, of the monuments consulted in geology, and those available in history, extends no farther than to one class of historical monuments—those which may be said to be *undesignedly* commemorative of former events. The buried coin fixes the date of the reign of some Roman emperor: the ancient encampment indicates the districts once occupied by invading armies, and the former method of constructing military defences; the Egyptian mummies throw light on the art of embalming, the rites of sepulture, or the average stature of the human race in ancient Egypt. The canoes and stone hatchets, called celts, found in our peat-bogs

and estuary deposits, afford an insight into the rude arts and manners of a prehistoric race, to whom the use of metals was unknown, while flint implements of a much ruder type point to a still earlier period, when man coexisted in Europe with many quadrupeds long since extinct. This class of memorials yields to no other in authenticity, but it constitutes a small part only of the resources on which the historian relies, whereas in geology it forms the only kind of evidence which is at our command. For this reason we must not expect to obtain a full and connected account of any series of events beyond the reach of history. But the testimony of geological monuments, if frequently imperfect, possesses at least the advantage of being free from all intentional misrepresentation. We may be deceived in the inferences which we draw, in the same manner as we often mistake the nature and import of phenomena observed in the daily course of nature; but our liability to err is confined to the interpretation, and, if this be correct, our information is certain.

It was long before the distinct nature and legitimate objects of geology were fully recognised, and it was at first confounded with many other branches of enquiry, just as the limits of history, poetry, and mythology were ill defined in the infancy of civilisation. Even in Werner's time, or at the close of the eighteenth century, geology appears to have been regarded as little other than a subordinate department of Mineralogy; and Desmarest included it under the head of Physical Geography. But the most common and serious source of confusion arose from the notion, that it was the business of geology to discover the mode in which the earth originated, or, as some imagined, to study the effects of those cosmological causes which were employed by the Author of Nature to bring this planet out of a nascent and chaotic state into a more perfect and habitable condition. Hutton was the first who endeavoured to draw a strong line of demarcation between his favourite science and cosmogony, for he declared that geology was in nowise concerned 'with questions as to the origin of things.'

An attempt will be made in the sequel of this work to

demonstrate that geology differs as widely from cosmogony, as speculations concerning the mode of the first creation of man differ from history. But, before entering more at large on this controverted question, it will be desirable to trace the progress of opinion on this topic, from the earliest ages to the commencement of the present century.

CHAPTER II.

ORIENTAL COSMOGONY—HYMNS OF THE VEDAS—INSTITUTES OF MENU—DOCTRINE OF THE SUCCESSIVE DESTRUCTION AND RENOVATION OF THE WORLD—ORIGIN OF THIS DOCTRINE—COMMON TO THE EGYPTIANS—ADOPTED BY THE GREEKS—ANAXIMANDER ON THE ORIGIN OF MANKIND FROM FISH—SYSTEM OF PYTHAGORAS—OF ARISTOTLE—DOGMAS CONCERNING THE EXTINCTION AND REPRODUCTION OF GENERA AND SPECIES—STRABO'S THEORY OF ELEVATION BY EARTHQUAKES—PLINY—CONCLUDING REMARKS ON THE KNOWLEDGE OF THE ANCIENTS.

Oriental Cosmogony.—The earliest doctrines of the Indian and Egyptian schools of philosophy agreed in ascribing the first creation of the world to an omnipotent and infinite Being. They concurred also in representing this Being, who had existed from all eternity, as having repeatedly destroyed and reproduced the world and all its inhabitants. In the sacred volume of the Hindoos, called the Ordinances of Menù, comprising the Indian system of duties religious and civil, we find a preliminary chapter treating of the Creation, in which the cosmogony is known to have been derived from earlier writings and traditions; and principally from certain hymns of high antiquity, called the Vedas. These hymns were first put together, according to Mr. Colebrooke,* in a connected series, about thirteen centuries before the Christian era, but they appear from internal evidence to have been written at various antecedent periods. In them, as we learn from the researches of Professor Wilson, the eminent Sanscrit scholar, two distinct philosophical systems are discoverable. According to one of them, all things were originally brought into existence by the sole will of a single First Cause, which existed from eternity; according to the other, there have always existed two principles, the one material, but without

* Essays on the Philosophy of the Hindoos.

form, the other spiritual and capable of compelling 'inert matter to develope its sensible properties.' This development of matter into 'individual and visible existences' is called creation, and is assigned to a subordinate agent, or the creative faculty of the Supreme Being embodied in the person of Brahma.

In the first chapter of the Ordinances of Menù above alluded to, we meet with the following passages relating to former destructions and renovations of the world:—

'The Being, whose powers are incomprehensible, having created me (Menù) and this universe, again became absorbed in the supreme spirit, changing the time of energy for the hour of repose.

'When that Power awakes, then has this world its full expansion; but when he slumbers with a tranquil spirit, then the whole system fades away. . . . . For while he reposes, as it were, embodied spirits endowed with principles of action depart from their several acts, and the mind itself becomes inert.'

The absorption of all beings into the Supreme essence is then described, and the Divine soul itself is said to slumber and to remain for a time immersed in 'the first idea, or in darkness.' After which the text thus proceeds (verse fifty-seven), 'Thus that immutable power by waking and reposing alternately, revivifies and destroys, in eternal succession, this whole assemblage of locomotive and immovable creatures.'

It is then declared that there has been a long succession of *manwantaras*, or periods, each of the duration of many thousand ages, and—

'There are creations also, and destructions of worlds innumerable: the Being, supremely exalted, performs all this with as much ease as if in sport, again and again, for the sake of conferring happiness.'*

No part of the Eastern cosmogony, from which these extracts are made, is more interesting to the geologist than the doctrine, so frequently alluded to, of the reiterated submersion of the land beneath the waters of an universal ocean.

* Institutes of Hindoo Law, or the Ordinances of Menù, from the Sanscrit, translated by Sir William Jones, 1796.

In the beginning of things, we are told, the First Sole Cause 'with a thought created the waters,' and then moved upon their surface in the form of Brahma the creator, by whose agency the emergence of the dry land was effected, and the peopling of the earth with plants, animals, celestial creatures, and man. Afterwards, as often as a general conflagration at the close of each manwantara had annihilated every visible and existing thing, Brahma, on awaking from his sleep, finds the whole world a shapeless ocean. Accordingly, in the legendary poem called the Puranas, composed at a later date than the Vedas, the three first Avatars or descents of the Deity upon earth have for their object to recover the land from the waters. For this purpose Vishnu is made successively to assume the form of a fish, a tortoise, and a boar.

Extravagant as may be some of the conceits and fictions which disfigure these pretended revelations, we can by no means look upon them as a pure effort of the unassisted imagination, or believe them to have been composed without regard to opinions and theories founded on the observation of Nature. In astronomy, for instance, it is declared that, at the North Pole, the year was divided into a long day and night, and that their long day was the northern, and their night the southern course of the sun; and to the inhabitants of the moon, it is said one day is equal in length to one month of mortals.* If such statements cannot be resolved into mere conjectures, we have no right to refer to chance alone the prevailing notion that the earth and its inhabitants had formerly undergone a succession of revolutions and aqueous catastrophes interrupted by long intervals of tranquillity.

Now, there are two sources in which such a theory may have originated. The marks of former convulsions on every part of the surface of our planet are obvious and striking. The remains of marine animals imbedded in the solid strata are so abundant, that they may be expected to force themselves on the attention of every people who have made some progress in refinement; and especially where one class of

* Menû, Inst. c. i. 66, and 67.

men are expressly set apart from the rest, like the ancient priesthoods of India and Egypt, for study and contemplation. If these appearances are once recognised, it seems natural that the mind should conclude in favour, not only of mighty changes in past ages, but of alternate periods of repose and disorder;—of repose, when the animals now fossil lived, grew and multiplied—of disorder, when the strata in which they were buried became transferred from the sea to the interior of continents, and were uplifted so as to form part of high mountain-chains. Those modern writers, who are disposed to disparage the former intellectual advancement and civilisation of Eastern nations, may concede some foundation of observed facts for the curious theories now under consideration, without indulging in exaggerated opinions of the progress of science; especially as universal catastrophes of the world, and exterminations of organic beings, in the sense in which they were understood by the Brahmins, are untenable doctrines.

We know that the Egyptian priests were aware, not only that the soil beneath the plains of the Nile, but that also the hills bounding the great valley, contained marine shells; and Herodotus inferred from these facts, that all lower Egypt, and even the high lands about Memphis, had once been covered by the sea.* As similar fossil remains occur in all parts of Asia hitherto explored, far in the interior of the continent as well as near the sea, they could hardly have escaped detection by some Eastern sages not less capable than the Greek historian of reasoning philosophically on natural phenomena.

We also know that the rulers of Asia were engaged in very remote eras in executing great national works, such as tanks and canals requiring extensive excavations. In the fourteenth century of our era (in the year 1360), the removal of soil necessary for such undertakings brought to light geological facts, which attracted the attention of a people less civilised than were many of the older nations of the East. The historian Ferishta relates that 50,000 labourers were employed in cutting through a mound, so as to form a junction

* Herodot. Euterpe, 12.

between the rivers Selima and Sutlej; and in this mound were found the bones of elephants and men, some of them petrified, and some of them resembling bone. The gigantic dimensions attributed to the human bones show them to have belonged to some of the larger pachydermata.*

But although the Brahmins, like the priests of Egypt, may have been acquainted with the existence of fossil remains in the strata, it is possible that the doctrine of successive destructions and renovations of the world, merely received corroboration from such proofs; and that it may have been originally handed down, like the religious traditions of most nations, from a ruder state of society. The system may have had its source, in part at least, in exaggerated accounts of those dreadful catastrophes, which are occasioned by particular combinations of natural causes. Floods and volcanic eruptions, the agency of water and fire, are the chief instruments of devastation on our globe. We shall point out in the sequel the extent of many of these calamities, recurring at distant intervals of time, in the present course of nature; and shall only observe here, that they are so peculiarly calculated to inspire a lasting terror, and are so often fatal in their consequences to great multitudes of people, that it scarcely requires the passion for the marvellous, so characteristic of rude and half-civilised nations, still less the exuberant imagination of Eastern writers, to augment them into general cataclysms and conflagrations.

The great flood of the Chinese, which their traditions carry back to the period of Yaou, something more than 2,000 years before our era, has been identified by some persons with the universal deluge described in the Old Testament; but according to Mr. Davis, who accompanied two of our embassies to China, and who has carefully examined their written accounts, the Chinese cataclysm is therein described as interrupting the business of agriculture, rather than as involving a general destruction of the human race. The

* A Persian MS. copy of the historian Ferishta, in the library of the East India Company, relating to the rise and progress of the Mahomedan empire in India, was procured by Colonel Briggs from the library of Tippoo Sultan in 1799; which has been referred to at some length by Dr. Buckland. (Geol. Trans. 2d Series, vol. ii. part iii. p. 389.)

great Yu was celebrated for having 'opened nine channels to draw off the waters,' which 'covered the low hills and bathed the foot of the highest mountains.' Mr. Davis suggests that a great derangement of the waters of the Yellow River, one of the largest in the world, might even now cause the flood of Yaou to be repeated, and lay the most fertile and populous plains of China under water. In modern times the bursting of the banks of an artificial canal, into which a portion of the Yellow River has been turned, has repeatedly given rise to the most dreadful accidents, and is a source of perpetual anxiety to the government. It is easy, therefore, to imagine how much greater may have been the inundation, if this valley was ever convulsed by a violent earthquake.*

Humboldt relates the interesting fact that, after the annihilation of a large part of the inhabitants of Cumana, by an earthquake in 1766, a season of extraordinary fertility ensued, in consequence of the great rains which accompanied the subterranean convulsions. 'The Indians,' he says, 'celebrated, after the ideas of an antique superstition, by festivals and dancing, the destruction of the world and the approaching epoch of its regeneration.'†

The existence of such rites among the rude nations of South America is most important, as showing what effects may be produced by local catastrophes, recurring at distant intervals of time, on the minds of a barbarous and uncultivated race. I shall point out in the sequel how the tradition of a deluge among the Araucanian Indians may be explained, by reference to great earthquake-waves which have repeatedly rolled over part of Chili since the first recorded flood of 1590. The legend also of the ancient Peruvians of an inundation many years before the reign of the Incas, in which only six persons were saved on a float, relates to a region which has more than once been overwhelmed by inroads of the ocean since the days of Pizarro. I might refer the reader to my account of the submergence of a wide area in Cutch so lately as the year 1819, when a single tower only of the fort of Sindree

* See Davis on 'The Chinese,' published by the Soc. for the Diffus. of Use. Know. vol. i. pp. 137, 147.

† Humboldt et Bonpland, Voy. Relat. Hist. vol. i. p. 30.

appeared above the waste of waters, if it were necessary, to prove how easily the catastrophes of modern times might give rise to traditionary narratives, among a rude people, of floods of boundless extent. Nations without written records, and who are indebted for all their knowledge of past events exclusively to oral tradition, are in the habit of confounding in one legend a series of incidents which have happened at various epochs; nor must we forget that the superstitions of a savage tribe are transmitted through all the progressive stages of society, till they exert a powerful influence on the mind of the philosopher. He may find, in the monuments of former changes on the earth's surface, an apparent confirmation of tenets handed down through successive generations, from the rude hunter, whose terrified imagination drew a false picture of those awful visitations of floods and earthquakes, whereby the whole earth as known to him was simultaneously devastated.

Egyptian Cosmogony.—Respecting the cosmogony of the Egyptian priests, we gather much information from writers of the Grecian sects, who borrowed almost all their tenets from Egypt, and amongst others that of the former successive destruction and renovation of the world.* We learn from Plutarch, that this was the theme of one of the hymns of Orpheus, so celebrated in the fabulous ages of Greece. It was brought by him from the banks of the Nile; and we even find in his verses, as in the Indian systems, a definite period assigned for the duration of each successive world.† The returns of great catastrophes were determined by the period of the Annus Magnus, or great year—a cycle composed of the revolutions of the sun, moon, and planets, and terminating when these return together to the same sign whence they were supposed at some remote epoch to have set out. The duration of this great cycle was variously estimated. According to Orpheus, it was 120,000 years; according to others, 300,000; and by Cassander it was taken to be 360,000 years.‡

We learn particularly from the Timæus of Plato, that the

* Prichard's Egypt. Mythol. p. 177.

† Plut. de Defectu Oraculorum, cap. 12. Censorinus de Die Natali. See also Prichard's Egypt. Mythol. p. 182.

‡ Prichard's Egypt. Mythol. p. 182.

Egyptians believed the world to be subject to occasional conflagrations and deluges, whereby the gods arrested the career of human wickedness, and purified the earth from guilt. After each regeneration, mankind were in a state of virtue and happiness, from which they gradually degenerated again into vice and immorality. From this Egyptian doctrine, the poets derived the fable of the decline from the golden to the iron age. The sect of Stoics adopted most fully the system of catastrophes destined at certain intervals to destroy the world. These they taught were of two kinds;—the Cataclysm or destruction by water, which sweeps away the whole human race, and annihilates all the animal and vegetable productions of nature; and the Ecpyrosis, or destruction by fire, which dissolves the globe itself. From the Egyptians also they derived the doctrine of the gradual debasement of man from a state of innocence. Towards the termination of each era the gods could no longer bear with the wickedness of men, and a shock of the elements or a deluge overwhelmed them; after which calamity, Astrea again descended on the earth, to renew the golden age.*

The connection between the doctrine of successive catastrophes and repeated deteriorations in the moral character of the human race is more intimate and natural than might at first be imagined. For, in a rude state of society, all great calamities are regarded by the people as judgments of God on the wickedness of man. Thus, in our own time, the priests persuaded a large part of the population of Chili, and perhaps believed themselves, that the fatal earthquake of 1822 was a sign of the wrath of Heaven for the great political revolution just then consummated in South America. In like manner, in the account given to Solon by the Egyptian priests, of the submersion of the island of Atlantis under the waters of the ocean, after repeated shocks of an earthquake, we find that the event happened when Jupiter had seen the moral depravity of the inhabitants.† Now, when the notion had once gained ground, whether from causes before suggested or not, that the earth had been destroyed by several general catastrophes, it would next be inferred that the

* Prichard's Egypt. Mythol. p. 193. † Plato's Timæus.

human race had been as often destroyed and renovated. And since every extermination was assumed to be penal, it could only be reconciled with divine justice, by the supposition that man, at each successive creation, was regenerated in a state of purity and innocence.

A very large portion of Asia, inhabited by the earliest nations whose traditions have come down to us, has been always subject to tremendous earthquakes. Of the geographical boundaries of these, and their effects, I shall speak in the proper place. Egypt has, for the most part, been exempt from this scourge, and the Egyptian doctrine of great catastrophes was probably derived in part, as before hinted, from early geological observations, and in part from Eastern nations.

In the Egyptian and Eastern cosmogonies, and in the Greek version of them, no very definite meaning can, in general, be attached to the term 'destruction of the world;' for sometimes it would seem almost to imply the annihilation of our planetary system, and at others a mere revolution of the surface of the earth.

One remarkable fiction of the Egyptian mythology was the supposed intervention of a masculo-feminine principle, to which was assigned the development of the embryo world from chaos, somewhat in the way of incubation. When the first chaotic mass had been produced by a self-dependent and eternal Being, it required the mysterious functions of this subordinate deity to produce the mundane egg from which the whole organised world was developed.

Aristophanes, alluding to this Egyptian fable, which had been engrafted by Orpheus on the Greek mythology, introduced the chorus in his comedy of 'The Birds' singing in a solemn hymn, 'How sable-plumaged Night conceived in the boundless bosom of Erebus, and laid an egg, from which, in the revolution of ages, sprang Love, resplendent with golden pinions. Love fecundated the dark-winged chaos, and gave origin to the race of birds.'*

It is not inconsistent with the Hindoo mythology to suppose that Pythagoras, whose opinions will presently be

* Aristophanes' Birds, p. 694.

mentioned, might have found in the East not only the system of universal and violent catastrophes and periods of repose in endless succession, but also that of periodical revolutions, effected by the continued agency of ordinary causes. For Brahma, Vishnu, and Siva, the first, second, and third persons of the Hindoo triad, severally represented the Creative, the Preserving, and the Destroying powers of the Deity. The co-existence of these three attributes, all in simultaneous operation, might well accord with the notion of perpetual but partial alterations finally bringing about a complete change. But the fiction expressed in the verses before quoted from Menù of eternal vicissitudes in the vigils and slumbers of Bramah seems accommodated to the system of great general catastrophes followed by new creations and periods of repose.

Opinions of the Greeks.—Anaximander (610 B.C.). In the 8th book of Plutarch's Symposiacon or 'Convivial Conversations,' the question is raised why the Pythagoreans were averse to eating fish, and it is considered whether the prejudice may have had an Egyptian, or a Syrian, or an ancient Greek source. One of the party alludes to the doctrine of Anaximander that 'Men were in the beginning engendered in fish, and after they had been nourished and had become able to shift for themselves, they were cast out and took to the land.' A suggestion is then made that, as fish were the parents of mankind, Anaximander may have objected to the use of them as food. Such allusions to an ancient doctrine by no means warrant us in assuming that Anaximander had really taught that men should abstain, from such a motive, from eating fish, but they are curious as affording evidence that the Milesian philosopher really believed that men originally sprang from fish. Unfortunately all the works of Anaximander, the pupil of Thales, are lost. He was born 610 years before Christ, and is said to have been the first who left a philosophical treatise in writing. It is only from a few brief citations scattered through the pages of later authors, that we learn anything of his opinions. Eusebius quotes from a lost work of Plutarch called Στρωματεῖς or 'patchwork,' the following words: 'Man, according to Anaximander, must have been born from animals of a different form (ἐξ ἀλλοειδῶν

ζώων); for whereas other animals easily get their food by themselves, man alone requires long rearing; and no one being such as he was originally, could have been preserved.' *

In another work of Plutarch we read as follows: 'Anaximander taught that the first animals (τὰ πρῶτα ζῶα) were begotten in moisture, and were covered with prickly integuments, but as they grew older they came out into the dry land, and their integuments were rent asunder.' † Censorinus, in his work 'De Die Natali,' says that, according to Anaximander, either fish, or animals very like fish, sprang from heated water and earth, and that the human fœtuses grew in these animals to a state of puberty, so that when at length they burst, men and women capable of nourishing themselves proceeded from them.‡ Full justice cannot, probably, be done to the views of this ancient author by reference to the few meagre fragments of his writings which have alone come down to us, but we trace the same idea running through all of them, namely, the peculiar helplessness of the human infant, making it natural to suppose that there must have been a connection between the embryonic condition of the first human beings and some previously existing animals. Anaximander evidently took for granted that man was not created in an adult or fully developed state, and in so doing he made at least some slight approach, twenty-five centuries before our time, to the modern doctrine of evolution. But none of the above passages warrant the conclusion that the Greek philosopher had anticipated the Lamarckian theory of progressive development. Yet H. Ritter, writing in 1819,§ represents him as having taught that after the first imperfect and short-lived creatures had been engendered in slime, an advance took place from the lower to the higher grades of life, until at length man was formed; and Cuvier, usually so accurate, but who seems never in this instance to have consulted the original texts, went a step beyond Ritter, and said, 'Anaximander pretended that men had been first fish,

* Euseb. Εὐαγγελικῆς προπαρ. 1-8.

† De Placidis Philosophorum, book v. chap. 19.

‡ Censorinus de Die Natali IV.

§ Ersch and Gruber's Encyclopedia, article *Anaximander*.

then reptiles, then mammalia, and lastly what they now are.' 'A system,' he adds, 'which we find reproduced in times very near to our own, and even in the nineteenth century.' 'Quoi qu'il en soit, Anaximandre, ayant admis l'eau comme le second principe de la Nature, prétendait que les hommes avaient primitivement été poissons, puis reptiles, puis mammifères et enfin ce qu'ils sont maintenant, nous retrouverons ce système dans des temps très-rapprochés des nôtres et même dans le dix-neuvième siècle.'*

Pythagorean Doctrines.—Pythagoras (580? B.C.), who resided for more than twenty years in Egypt, and, according to Cicero, had visited the East, and conversed with the Persian philosophers, introduced into his own country, on his return, the doctrine of the gradual deterioration of the human race from an original state of virtue and happiness; but if we are to judge of his theory concerning the destruction and renovation of the earth from the sketch given by Ovid, we must concede it to have been far more philosophical than any known version of the cosmogonies of Oriental or Egyptian sects.

Although Pythagoras is introduced by the poet as delivering his doctrine in person, some of the illustrations are derived from natural events which happened after the death of the philosopher. But notwithstanding these anachronisms, we may regard the account as a true picture of the tenets of the Pythagorean school in the Augustan age; and although perhaps partially modified, it must have contained the substance of the original scheme. Thus considered, it is extremely curious and instructive; for we here find a comprehensive summary of almost all the great causes of change now in activity on the globe, and these adduced in confirmation of a principle of a perpetual and gradual revolution inherent in the nature of our terrestrial system. These doctrines, it is true, are not directly applied to the explanation of geological phenomena; or, in other words, no attempt is made to estimate what may have been in past ages, or what

* Cuvier, Hist. des Sciences naturelles, tome i. p. 91, published in 1841. Lamarck and Geoffroy St. Hilaire are evidently here alluded to: they had derived their theory of progressive development from geological data, the former having published his opinions in 1801, and G. St. Hilaire in 1828.

may hereafter be, the aggregate amount of change brought about by such never-ending fluctuations. Had this been the case, we might have been called upon to admire so extraordinary an anticipation with no less interest than astronomers, when they endeavour to define by what means the Samian philosopher came to the knowledge of the Copernican system.

Let us now examine the celebrated passages to which we have been adverting :—*

'Nothing perishes in this world; but things merely vary and change their form. To be born, means simply that a thing begins to be something different from what it was before; and dying, is ceasing to be the same thing. Yet, although nothing retains long the same image, the sum of the whole remains constant.' These general propositions are then confirmed by a series of examples, all derived from natural appearances, except the first, which refers to the golden age giving place to the age of iron. The illustrations are thus consecutively adduced.

1. Solid land has been converted into sea.

2. Sea has been changed into land. Marine shells lie far distant from the deep, and the anchor has been found on the summit of hills.

3. Valleys have been excavated by running water, and floods have washed down hills into the sea.†

4. Marshes have become dry ground.

5. Dry lands have been changed into stagnant pools.

6. During earthquakes some springs have been closed up, and new ones have broken out. Rivers have deserted their channels, and have been re-born elsewhere; as the Erasinus in Greece, and Mysus in Asia.

7. The waters of some rivers, formerly sweet, have become bitter; as those of the Anigris in Greece, &c.‡

8. Islands have become connected with the main land by

* Ovid's Metamor. lib. 15.

† Eluvie mons est deductus in æquor, v. 267. The meaning of this last verse is somewhat obscure; but taken with the context, may be supposed to allude to the abrading power of floods, torrents, and rivers.

‡ The impregnation from new mineral springs, caused by earthquakes in volcanic countries, is perhaps here alluded to.

the growth of deltas and new deposits; as in the case of Antissa joined to Lesbos, Pharos to Egypt, &c.

9. Peninsulas have been divided from the main land, and have become islands, as Leucadia; and according to tradition Sicily, the sea having carried away the isthmus.

10. Land has been submerged by earthquakes; the Grecian cities of Helice and Buris, for example, are to be seen under the sea, with their walls inclined.

11. Plains have been upheaved into hills by the confined air seeking vent, as at Trœzene in the Peloponnesus.

12. The temperature of some springs varies at different periods. The waters of others are inflammable.* Some streams make the hair to resemble amber and gold, others influence the mind as well as the body, having some of them an exciting, others a soporific effect.

13. There are streams which have a petrifying power, and convert the substances which they touch into marble.

14. Extraordinary medicinal and deleterious effects are produced by water of different lakes and springs.†

15. Some rocks and islands, after floating and having been subject to violent movements, have at length become stationary and immovable, as Delos, and the Cyanean Isles.‡

16. Volcanic vents shift their position; there was a time when Etna was not a burning mountain, and the time will come when it will cease to burn. Whether it be that some caverns become closed up by the movements of the earth, and others opened, or whether the fuel is finally exhausted, &c. &c.

The various causes of change in the inanimate world

* This is probably an allusion to the escape of inflammable gas, like that in the district of Baku, west of the Caspian; at Pietramala, in the Tuscan Apennines; and several other places.

† Many of those described seem fanciful fictions, like the exaggerated virtues still attributed to some mineral waters.

‡ Raspe, in a learned and judicious essay (De Novis Insulis, cap. 19), has made it appear extremely probable that all the traditions of certain islands in the Mediterranean having at some former time frequently shifted their positions, and at length become stationary, originated in the great change produced in their form by earthquakes and submarine eruptions, of which there have been modern examples in the new islands raised in the time of history. When the series of convulsions ended, the island was said to become fixed.

having been thus enumerated, those of the animate creation are next alluded to. The metamorphoses of insects and frogs are mentioned, and some popular notions respecting other changes in the organic world, such as the springing up of the phœnix from the ashes of its parent; but none of the facts or fables have any geological bearing, unless we consider the alleged generation of bees and wasps from the putrid carcases of dead cattle and horses, and the originating of snakes from the marrow of the human spine in sepulchres, as implying the adoption of the doctrine of equivocal generation. The transmigration of souls into the bodies of animals is referred to as having been taught by Numa Pompilius. But there is nothing to prove that the Greeks or Romans had any fixed ideas respecting a general change of species having occurred in the past history of the globe, still less that there had been a progressive development of life from the lowest to the highest grades of organisation. Xenophanes, a Colophonian who lived B.C. 535, spoke of shells, fishes, and seals which had become dried in mud, and were found inland and on the tops of the highest mountains. Aristotle, in his treatise on respiration, speaks distinctly of fossil fishes; and his pupil Theophrastus, alluding to such fishes found near Heraclea, in Pontus, and in Paphlagonia, says, that they were either procreated from fish-spawn left behind in the earth, or had gone astray from rivers or from the sea, for the sake of food, into cavities in the earth, where they had become petrified. The same writer, treating of fossil ivory and bones, supposed them to be produced by a certain plastic virtue latent in our earth.

Opinions of Aristotle.—From the works now extant of Aristotle, and from the system of Pythagoras, as above exposed, we might certainly infer that these philosophers considered the agents of change now operating in nature, as capable of bringing about in the lapse of ages a complete revolution; and the Stagyrite even considers occasional catastrophes, happening at distant intervals of time, as part of the regular and ordinary course of nature. The deluge of Deucalion, he says, affected Greece only, and principally the part called Hellas, and it arose from great inundations of

rivers during a rainy winter. But such extraordinary winters, he says, though after a certain period they return, do not always revisit the same places.*

Censorinus quotes it as Aristotle's opinion, that there were general inundations of the globe, and that they alternated with conflagrations; and that the flood constituted the winter of the Great Year, or astronomical cycle, while the conflagration, or destruction by fire, is the summer or period of greatest heat.† If this passage, as Lipsius supposes, be an amplification, by Censorinus, of what is written in 'the Meteorics,' it is a gross misrepresentation of the doctrine of the Stagyrite, for the general bearing of his reasoning in that treatise tends clearly in an opposite direction. He refers to many examples of changes now constantly going on, and insists emphatically on the great results which they must produce in the lapse of ages. He instances particular cases of lakes that had dried up, and deserts that had at length become watered by rivers and fertilised. He points to the growth of the Nilotic Delta since the time of Homer, to the shallowing of the Palus Mæotis within sixty years from his own time; and although, in the same chapter, he says nothing of changes in the relative level of land and sea, yet in other parts of the same treatise he speaks of such events in connection with earthquakes.‡ He alludes, for example, to the upheaving of one of the Eolian islands previous to a volcanic eruption. 'The changes of the earth,' he says, 'are so slow in comparison to the duration of our lives, that they are overlooked (λανθάνει); and the migrations of people after great catastrophes and their removal to other regions, cause the event to be forgotten.'§

When we consider the acquaintance displayed by Aristotle, in his various works, with the destroying and renovating powers of Nature, the introductory and concluding passages of the twelfth chapter of his 'Meteorics' are certainly very remarkable. In the first sentence he says, 'The distribution of land and sea in particular regions does not endure throughout all time, but it becomes sea in those parts where

* Meteor. lib. i. cap. 12.
† De Die Nat.
‡ Lib. ii. cap. 14, 15, and 16.
§ Ibid.

it was land, and again it becomes land where it was sea: and there is reason for thinking that these changes take place according to a certain system, and within a certain period.' The concluding observation is as follows:—'As time never fails, and the universe is eternal, neither the Tanais, nor the Nile, can have flowed for ever. The places where they rise were once dry, and there is a limit to their operations: but there is none to time. So also of all other rivers; they spring up, and they perish; and the sea also continually deserts some lands and invades others. The same tracts, therefore, of the earth are not, some always sea, and others always continents, but everything changes in the course of time.'

It seems, then, that the Greeks had not only derived from preceding nations, but had also, in some slight degree, deduced from their own observations, the theory of periodical revolutions in the inorganic world: there is, however, no ground for imagining that they contemplated former changes in the races of animals and plants. Even the fact that marine remains were enclosed in solid rocks, although observed by some, and even made the groundwork of geological speculation, never stimulated the industry or guided the enquiries of naturalists. It is not impossible that the theory of equivocal generation might have engendered some indifference on this subject, and that a belief in the spontaneous production of living beings from the earth or corrupt matter, might have caused the organic world to appear so unstable and fluctuating, that phenomena indicative of former changes would not awaken intense curiosity. The Egyptians, it is true, had taught, and the Stoics had repeated, that the earth had once given birth to some monstrous animals, which existed no longer; but the prevailing opinion seems to have been, that after each great catastrophe the same species of animals were created over again. This tenet is implied in a passage of Seneca, where, speaking of a future deluge, he says, 'Every animal shall be generated anew, and man free from guilt shall be given to the earth.'*

* 'Omne ex integro animal generabitur, dabiturque terris homo inscius scelerum.'—Quæst. Nat. iii. c. 29.

An old Arabian version of the doctrine of the successive revolutions of the globe, translated by Abraham Ecchellensis,* seems to form a singular exception to the general rule, for here we find the idea of different genera and species having been created. The Gerbanites, a sect of astronomers who flourished some centuries before the Christian era, taught as follows:—'That after every period of thirty-six thousand four hundred and twenty years, there were produced a pair of *every* species of animal, both male and female, from whom animals might be propagated and inhabit this lower world. But when a circulation of the heavenly orbs was completed, which is finished in that space of years, *other genera and species* of animals are propagated, as also of plants and other things, and the first order is destroyed, and so it goes on for ever and ever.'†

Theory of Strabo.—As we learn much of the tenets of the Egyptian and Oriental schools in the writings of the Greeks, so, many speculations of the early Greek authors are made known to us in the works of the Augustan and later ages. Strabo, in particular, enters largely, in the second book of his Geography, into the opinions of Eratosthenes and other Greeks on one of the most difficult problems in geology, viz. by what cause marine shells came to be plentifully buried in the earth at such great elevations and distances from the sea.

* This author was Regius Professor of Syriac and Arabic at Paris, where, in 1685, he published a Latin translation of many Arabian MSS. on different departments of philosophy. This work has always been considered of high authority.

† 'Gerbanitæ docebant singulos triginta sex mille annos quadringentos, viginti quinque bina ex singulis animalium speciebus produci, marem scilicet ac feminam ex quibus animalia propagantur, huncque inferiorem incolunt orbem. Absolutâ autem cœlestium orbium circulatione, quæ illo annorum conficitur spatio, iterum alia producuntur animalium genera et species, quemadmodum et plantarum aliarumque rerum, et primus destruitur ordo, sicque in infinitum producitur.'—Histor.Orient. Suppl. per Abrahamum Ecchellensem, Syrum Maronitam, cap. 7 et 8, ad calcem Chronici Orientali. Parisiis, e Typ. Regia, 1685, fol.

I have given the punctuation as in the Paris edition, there being no comma after quinque; but, at the suggestion of M. de Schlegel, I have referred the number twenty-five to the period of years, and not to the number of pairs of each species created at one time, as I had done in the two first editions.

Fortis inferred that twenty-five new *species* only were created at a time; a construction which the passage will not admit. Mém. sur l'Hist. nat. de l'Italie, vol. i. p. 202.

He notices, amongst others, the explanation of Xanthus the Lydian, who said that the seas had once been more extensive, and that they had afterwards been partially dried up, as in his own time many lakes, rivers, and wells in Asia had failed during a season of drought. Treating this conjecture with merited disregard, Strabo passes on to the hypothesis of Strato, the natural philosopher, who had observed that the quantity of mud brought down by rivers into the Euxine was so great, that its bed must be gradually raised, while the rivers still continued to pour in an undiminished quantity of water. He therefore conceived that, originally, when the Euxine was an inland sea, its level had by this means become so much elevated that it burst its barrier near Byzantium, and formed a communication with the Propontis; and this partial drainage, he supposed, had already converted the left side into marshy ground, and thus, at last, the whole would be choked up with soil. So, it was argued, the Mediterranean had once opened a passage for itself by the Columns of Hercules into the Atlantic; and perhaps the abundance of sea-shells in Africa, near the Temple of Jupiter Ammon, might also be the deposit of some former inland sea, which had at length forced a passage and escaped.

But Strabo rejects this theory, as insufficient to account for all the phenomena, and he proposes one of his own, the profoundness of which modern geologists are only beginning to appreciate. 'It is not,' he says, 'because the lands covered by seas were originally at different altitudes, that the waters have risen, or subsided, or receded from some parts and inundated others. But the reason is, that the same land is sometimes raised up and sometimes depressed, and the sea also is simultaneously raised and depressed, so that it either overflows or returns into its own place again. We must, therefore, ascribe the cause to the ground, either to that ground which is under the sea, or to that which becomes flooded by it, but rather to that which lies beneath the sea, for this is more movable and, on account of its humidity, can be altered with greater celerity.* *It is proper,*' he

* 'Quod enim hoc attollitur aut subsidit, et vel inundat quædam loca, vel ab iis recedit, ejus rei causa non est, quod alia aliis sola humiliora sint aut

observes in continuation, '*to derive our explanations from things which are obvious, and in some measure of daily occurrence, such as deluges, earthquakes, and volcanic eruptions,* and sudden swellings of the land beneath the sea*; for the last raise up the sea also; and when the same lands subside again, they occasion the sea to be let down. And it is not merely the small, but the large islands also, and not merely the islands, but the continents which can be lifted up together with the sea; and both large and small tracts may subside, for habitations and cities, like Bure, Bizona, and many others, have been engulphed by earthquakes.'

In another place this learned geographer, in alluding to the tradition that Sicily had been separated by a convulsion from Italy, remarks, that at present the land near the sea in those parts was rarely shaken by earthquakes, since there were now open orifices whereby fire and ignited matters, and waters escape; but formerly, when the volcanos of Etna, the Lipari Islands, Ischia, and others, were closed up, the imprisoned fire and wind might have produced far more vehement movements.† The doctrine, therefore, that volcanos are safety-valves, and that the subterranean convulsions are probably most violent when first the volcanic energy shifts itself to a new quarter, is not modern.

We learn from a passage in Strabo,‡ that it was a dogma of the Gaulish Druids that the universe was immortal, but destined to survive catastrophes both of fire and water. That this doctrine was communicated to them from the East, with much of their learning, cannot be doubted. Cæsar, it will be remembered, says that they made use of Greek letters in arithmetical computations.§

Pliny, A.D. 23. — This philosopher had no theoretical

altiora; sed quod idem solum modò attollitur modò deprimitur, simulque etiam modò attollitur modò deprimitur, mare: itaque vel exundat vel in suum redit locum.'

Posteà, p. 88. 'Restat, ut causam adscribamus solo, sive quod mari subest sive quod inundatur; potiùs tamen ei quod mari subest. Hoc enim multò est mobilius, et quod ob humiditatem celeriùs multari possit.'—Strabo, Geog. Edit. Almelov. Amst. 1707, lib. i.

* *Volcanic eruptions*, eruptiones flatuum, in the Latin translations, and in the original Greek, ἀναφυσήματα, gaseous eruptions? or *inflations* of land? Ibid. p. 93.

† Strabo, lib. vi. p. 396.

‡ Book iv.

§ L. vi. ch. xiii.

opinions of his own concerning changes of the earth's surface; and in this department, as in others, he restricted himself to the task of a compiler, without reasoning on the facts stated by him, or attempting to digest them into regular order. But his enumeration of the new islands which had been formed in the Mediterranean, and of other convulsions, shows that the ancients had not been inattentive observers of the changes which had taken place within the memory of man.

Such, then, appear to have been the opinions entertained before the Christian era, concerning the past revolutions of our globe. Although no particular investigations had been made for the express purpose of interpreting the monuments of ancient changes, they were too obvious to be entirely disregarded; and the observation of the present course of nature presented too many proofs of alterations continually in progress on the earth to allow philosophers to believe that nature was in a state of rest, or that the surface had remained, and would continue to remain, unaltered. But they had never compared attentively the results of the destroying and reproductive operations of modern times with those of remote eras, nor had they ever entertained so much as a conjecture concerning the comparative antiquity of the human race, or of living species of animals and plants, with those belonging to former conditions of the organic world. They had studied the movements and positions of the heavenly bodies with laborious industry, and made some progress in investigating the animal, vegetable, and mineral kingdoms; but the ancient history of the globe was to them a sealed book, and, although written in characters of the most striking and imposing kind, they were unconscious even of its existence.

CHAPTER III.

HISTORY OF THE PROGRESS OF GEOLOGY—*continued.*

ARABIAN WRITERS OF THE TENTH CENTURY—AVICENNA—OMAR—COSMOGONY OF THE KORAN—KAZWINI—EARLY ITALIAN WRITERS—LEONARDO DA VINCI—FRACASTORO—CONTROVERSY AS TO THE REAL NATURE OF FOSSILS—ATTRIBUTED TO THE MOSAIC DELUGE—PALISSY—STENO—SCILLA—QUIRINI—BOYLE—LISTER—LEIBNITZ—HOOKE'S THEORY OF ELEVATION BY EARTHQUAKES—OF LOST SPECIES OF ANIMALS—RAY—PHYSICO-THEOLOGICAL WRITERS—WOODWARD'S DILUVIAL THEORY—BURNET—WHISTON—VALLISNERI—LAZZARO MORO—GENERELLI—BUFFON—HIS THEORY CONDEMNED BY THE SORBONNE AS UNORTHODOX—HIS DECLARATION—TARGIONI—ARDUINO—MICHELL—CATCOTT—RASPE—FUCHSEL—FORTIS—TESTA—WHITEHURST—PALLAS—SAUSSURE.

ARABIAN WRITERS.—After the decline of the Roman empire, the cultivation of physical science was first revived with some success by the Saracens, about the middle of the eighth century of our era. The works of the most eminent classic writers were purchased at great expense from the Christians, and translated into Arabic; and Al Mamûn, son of the famous Harûn-al-Rashid, the contemporary of Charlemagne, received with marks of distinction, at his court at Bagdad, astronomers and men of learning from different countries. This caliph, and some of his successors, encountered much opposition and jealousy from the doctors of the Mahometan law, who wished the Moslems to confine their studies to the Koran, dreading the effects of a diffusion of a taste for the physical sciences.*

Avicenna.—Almost all the works of the early Arabian writers are lost. Amongst those of the tenth century, of which fragments are now extant, is a short treatise, 'On the Formation and Classification of Minerals,' by Avicenna, a physician,

* Mod. Univ. Hist. vol. ii. chap. iv. section iii.

in whose arrangement there is considerable merit. The second chapter, 'On the Cause of Mountains,' is remarkable; for mountains, he says, are formed, some by essential, others by accidental causes. In illustration of the essential, he instances 'a violent earthquake, by which land is elevated, and becomes a mountain;' of the accidental, the principal, he says, is excavation by water, whereby cavities are produced, and adjoining lands made to stand out and form eminences.*

Omar—Cosmogony of the Koran.—In the same century also, Omar, surnamed 'El Aalem,' or 'The Learned,' wrote a work on 'The Retreat of the Sea.' It appears that on comparing the charts of his own time with those made by the Indian and Persian astronomers two thousand years before, he had satisfied himself that important changes had taken place since the times of history in the form of the coasts of Asia, and that the extension of the sea had been greater at some former periods. He was confirmed in this opinion by the numerous salt springs and marshes in the interior of Asia,—a phenomenon from which Pallas, in more recent times, has drawn the same inference.

Von Hoff has suggested, with great probability, that the changes in the level of the Caspian (some of which there is reason to believe have happened within the historical era), and the geological appearances in that district, indicating the desertion by that sea of its ancient bed, had probably led Omar to his theory of a general lowering of the waters. But whatever may have been the proofs relied on, his system was declared contradictory to certain passages in the Koran, and he was called upon publicly to recant his errors; to avoid which persecution he went into voluntary banishment from Samarkand.†

* 'Montes quandòque fiunt ex causa essentiali, quandòque ex causa accidentali. Ex essentiali causa, ut ex vehementi motu terræ elevatur terra, et fit mons. Accidentali, &c.'—De Congelatione Lapidum, ed. Gedani, 1682.

† Von Hoff, Geschichte der Veränderungen der Erdoberfläche, vol. i. p. 406, who cites Delisle, bey Hismann, Welt- und Völkergeschichte. Alte Geschichte, 1ter Theil, s. 234.—The Arabian persecutions for heretical dogmas in theology were often very sanguinary. In the same ages wherein learning was most in esteem, the Mahometans were divided into two sects, one of whom maintained that the Koran was increate and had subsisted in the very essence of God for all eternity; and the other, the Motazalites, who, admitting that the

The cosmological opinions expressed in the Koran are few, and merely introduced incidentally: so that it is not easy to understand how they could have interfered so seriously with free discussion on the former changes of the globe. The Prophet declares that the earth was created in two days, and the mountains were then placed on it; and during these, and two additional days, the inhabitants of the earth were formed; and in two more the seven heavens.* There is no more detail of circumstances; and the deluge, which is also mentioned, is discussed with equal brevity. The waters are represented to have poured out of an oven; a strange fable, said to be borrowed from the Persian Magi, who represented them as issuing from the oven of an old woman.† All men were drowned, save Noah and his family; and then God said, 'O earth, swallow up thy waters; and thou, O heaven, withhold thy rain;' and immediately the waters abated.‡

We may suppose Omar to have represented the desertion of the land by the sea to have been gradual, and that his hypothesis required a greater lapse of ages than was consistent with Moslem orthodoxy; for it is to be inferred from the Koran, that man and this planet were created at the same time; and although Mahomet did not limit expressly the antiquity of the human race, yet he gave an implied sanction to the Mosaic chronology, by the veneration expressed by him for the Hebrew Patriarchs.§

A manuscript work, entitled the 'Wonders of Nature,' is preserved in the Royal Library at Paris, by an Arabian writer, Mohammed Kazwini, who flourished in the seventh century of the Hegira, or at the close of the thirteenth century of our era.|| Besides several curious remarks on aerolites,

Koran was instituted by God, conceived it to have been first made when revealed to the Prophet at Mecca, and accused their opponents of believing in two eternal beings. The opinions of each of these sects were taken up by different caliphs in succession, and the followers of each sometimes submitted to be beheaded, or flogged till at the point of death, rather than renounce their creed.—Mod. Univ. Hist. vol. ii. ch. iv.

* Koran, chap. xli.

† Sale's Koran, chap. xi. see note.

‡ Ibid.

§ Kossa, appointed master to the Caliph Al Mamûd, was author of a book entitled 'The History of the Patriarchs and Prophets, *from the Creation of the World*.'—Mod. Univ. Hist. vol. ii. ch. iv.

|| Translated by MM. Chezy and De Sacy, and cited by M. Elie de Beaumont. Ann. des Sci. nat. 1832.

earthquakes, and the successive changes of position which the land and sea have undergone, we meet with the following beautiful passage which is given as the narrative of Kidhz, an allegorical personage:—'I passed one day by a very ancient and wonderfully populous city, and asked one of its inhabitants how long it had been founded. "It is indeed a mighty city," replied he; "we know not how long it has existed, and our ancestors were on this subject as ignorant as ourselves." Five centuries afterwards, as I passed by the same place, I could not perceive the slightest vestige of the city. I demanded of a peasant, who was gathering herbs upon its former site, how long it had been destroyed. "In sooth a strange question!" replied he. "The ground here has never been different from what you now behold it."—"Was there not of old," said I, "a splendid city here?"—"Never," answered he, "so far as we have seen, and never did our fathers speak to us of any such." On my return there 500 years afterwards, *I found the sea in the same place*, and on its shores were a party of fishermen, of whom I enquired how long the land had been covered by the waters? "Is this a question," said they, "for a man like you? this spot has always been what it is now." I again returned, 500 years afterwards, and the sea had disappeared; I enquired of a man who stood alone upon the spot, how long ago this change had taken place, and he gave me the same answer as I had received before. Lastly, on coming back again after an equal lapse of time, I found there a flourishing city, more populous and more rich in beautiful buildings than the city I had seen the first time, and when I would fain have informed myself concerning its origin, the inhabitants answered me, "Its rise is lost in remote antiquity: we are ignorant how long it has existed, and our fathers were on this subject as ignorant as ourselves."'

Early Italian Writers.—It was not till the earlier part of the sixteenth century that geological phenomena began to attract the attention of the Christian nations. At that period a very animated controversy sprang up in Italy, concerning the true nature and origin of marine shells, and other organised fossils. found abundantly in the strata of the peninsula. The cele-

brated painter Leonardo da Vinci, who in his youth had planned and executed some navigable canals in the north of Italy, was one of the first who applied sound reasoning to these subjects. The mud of rivers, he said, had covered and penetrated into the interior of fossil shells at a time when these were still at the bottom of the sea near the coast. 'They tell us that these shells were formed in the hills by the influence of the stars; but I ask where in the hills are the stars now forming shells of distinct ages and species? and how can the stars explain the origin of gravel, occurring at different heights and composed of pebbles rounded as if by the motion of running water; or in what manner can such a cause account for the petrifaction in the same places of various leaves, sea-weeds, and marine crabs?' *

The excavations made in 1517, for repairing the city of Verona, brought to light a multitude of curious petrifactions, and furnished matter for speculation to different authors, and among the rest to Fracastoro,† who declared his opinion, that fossil shells had all belonged to living animals, which had formerly lived and multiplied where their exuviæ are now found. He exposed the absurdity of having recourse to the 'plastic force' of Theophrastus (see above, p. 20) which had power to fashion stones into organic forms; and with no less cogent arguments, demonstrated the futility of attributing the situation of the shells in question to the Mosaic deluge, a theory obstinately defended by some. That inundation, he observed, was too transient: it consisted principally of fluviatile waters; and if it had transported shells to great distances, must have strewed them over the surface, not buried them at vast depths in the interior of mountains. His clear exposition of the evidence would have terminated the discussion for ever, if the passions of mankind had not been enlisted in the dispute; and even though doubts should for a time have remained in some minds, they would

* See Venturi's extracts from Da Vinci's MSS. now in Library of Institute of France. They are not mentioned by Brocchi, and my attention was first called to them by Mr. Hallam. L. da Vinci died A.D. 1519.

† Museum Calceol.—See Brocchi's Discourse on the Progress of the Study of Fossil Conchology in Italy, where some of the following notices on Italian writers will be found more at large.

speedily have been removed by the fresh information obtained almost immediately afterwards, respecting the structure of fossil remains, and of their living analogues.

But the clear and philosophical views of Fracastoro were disregarded, and the talent and the argumentative powers of the learned were doomed for three centuries to be wasted in the discussion of these two simple and preliminary questions; first, whether fossil remains had ever belonged to living creatures; and, secondly, whether, if this be admitted, all the phenomena could not be explained by the deluge of Noah. It had been the general belief of the Christian world down to the period now under consideration, that the origin of this planet was not more remote than a few thousand years; and that since the creation the deluge was the only great catastrophe by which considerable change had been wrought on the earth's surface. On the other hand, the opinion was scarcely less general, that the final dissolution of our system was an event to be looked for at no distant period. The era, it is true, of the expected millennium had passed away; and for five hundred years after the fatal hour when the annihilation of the planet had been looked for, the monks remained in undisturbed enjoyment of rich grants of land bequeathed to them by pious donors, who, in the preamble of deeds beginning 'appropinquante mundi termino'——'appropinquante magno judicii die,' left lasting monuments of the popular delusion.*

But although in the sixteenth century it had become necessary to interpret certain prophecies respecting the millennium more liberally, and to assign a more distant date to the future conflagration of the world, we find, in the speculations of the early geologists, perpetual allusion to such an approaching catastrophe; while in all that regarded the antiquity of the earth, no modification whatever of the opinions of the dark ages had been effected. Considerable alarm was at first excited when the attempt was made to invalidate, by physical proofs, an article of faith so generally

* In Sicily, in particular, the title-deeds of many valuable grants of land to the monasteries are headed by such preambles, composed by the testators about the period when the good King Roger was expelling the Saracens from that island.

received; but there was sufficient spirit of toleration and candour amongst the Italian ecclesiastics, to allow the subject to be canvassed with much freedom. They even entered warmly into the controversy themselves, often favouring different sides of the question; and however much we may deplore the loss of time and labour devoted to the defence of untenable positions, it must be conceded that they displayed far less polemic bitterness than certain writers who followed them 'beyond the Alps,' two centuries and a half later.

CONTROVERSY AS TO THE REAL NATURE OF FOSSIL ORGANIC REMAINS.

Mattioli—Falloppio, 1500–1523.—The system of scholastic disputations, encouraged in the universities of the middle ages, had unfortunately trained men to habits of indefinite argumentation; and they often preferred absurd and extravagant propositions, because greater skill was required to maintain them; the end and object of these intellectual combats being victory, and not truth. No theory could be so far-fetched or fantastical as not to attract some followers, provided it fell in with popular notions; and as cosmogonists were not at all restricted, in building their systems, to the agency of known causes, the opponents of Fracastoro met his arguments by feigning imaginary causes, which differed from each other rather in name than in substance. Andrew Mattioli, for instance, an eminent botanist, the illustrator of Dioscorides, embraced the notion of Agricola, a skilful German miner, that a certain 'materia pinguis,' or 'fatty matter,' set into fermentation by heat, gave birth to fossil organic shapes. Yet Mattioli had come to the conclusion, from his own observations, that porous bodies, such as bones and shells, might be converted into stone, as being permeable to what he termed the 'lapidifying juice.' In like manner, Falloppio of Padua conceived that petrified shells were generated by fermentation in the spots where they are found, or that they had in some cases acquired their form from 'the tumultuous movements of terrestial exhalations.' Although celebrated as a professor of anatomy, he taught

that certain tusks of elephants, dug up in his time in Apulia, were mere earthy concretions; and, consistently with these principles, he even went so far as to consider it probable, that the vases of Monte Testaceo at Rome were natural impressions stamped in the soil.* In the same spirit, Mercati, who published, in 1574, faithful figures of the fossil shells preserved by Pope Sixtus V. in the Museum of the Vatican, expressed an opinion that they were mere stones, which had assumed their peculiar configuration from the influence of the heavenly bodies: and Olivi of Cremona, who described the fossil remains of a rich museum at Verona, was satisfied with considering them as mere 'sports of nature.'

Some of the fanciful notions of those times were deemed less unreasonable, as being somewhat in harmony with the Aristotelian theory of spontaneous generation, then taught in all the schools.† For men who had been taught in early youth, that a large proportion of living animals and plants were formed from the fortuitous concourse of atoms, or had sprung from the corruption of organic matter, might easily persuade themselves, that organic shapes, often imperfectly preserved in the interior of solid rocks, owed their existence to causes equally obscure and mysterious.

Cardano, 1552.—But there were not wanting some who, during the progress of this century, expressed more sound and sober opinions. The title of a work of Cardano's, published in 1552, 'De Subtilitate' (corresponding to what would now be called Transcendental Philosophy), would lead us to expect, in the chapter on minerals, many far-fetched theories characteristic of that age; but when treating of petrified shells, he decided that they clearly indicated the former sojourn of the sea upon the mountains.‡

Cesalpino—Majoli, 1597.—Cesalpino, a celebrated botanist, conceived that fossil shells had been left on the land by the retiring sea, and had concreted into stone during the consolidation of the soil; § and in the following year (1597), Simeone Majoli ‖ went still farther; and, coinciding for the most

* De Fossilib. pp. 109 and 176.

† Aristotle, On Animals, chapters 1 and 15.

‡ Brocchi, Con. Fos. Subap. Disc. sui Progressi. vol. i. p. 57.

§ De Metallicis.

‖ Dies Caniculares.

part with the views of Cesalpino, suggested that the shells and submarine matter of the Veronese, and other districts, might have been cast up upon the land by volcanic explosions, like those which gave rise, in 1538, to Monte Nuovo, near Puzzuoli. This hint seems to have been the first imperfect attempt to connect the position of fossil shells with the agency of volcanos, a system afterwards more fully developed by Hooke, Lazzaro Moro, Hutton, and other writers.

Two years afterwards, Imperati advocated the animal origin of fossil shells, yet admitted that stones could vegetate by force of 'an internal principle;' and, as evidence of this, he referred to the teeth of fish and spines of echini found petrified.*

Palissy, 1580.—Palissy, a French writer on 'The Origin of Springs from Rain-water,' and of other scientific works, undertook, in 1580, to combat the notions of many of his contemporaries in Italy, that petrified shells had all been deposited by the universal deluge. 'He was the first,' said Fontenelle, when, in the French Academy, he pronounced his eulogy, nearly a century and a half later, 'who dared assert,' in Paris, that fossil remains of testacea and fish had once belonged to marine animals.

Fabio Colonna, 1592.—To enumerate the multitude of Italian writers, who advanced various hypotheses, all equally fantastical, in the early part of the seventeenth century, would be unprofitably tedious; but Fabio Colonna deserves to be distinguished; for, although he gave way to the dogma, that all fossil remains were to be referred to the deluge of Noah, he resisted the absurd theory of Stelluti, who taught that fossil wood and ammonites were mere clay, altered into such forms by sulphureous waters and subterranean heat; and he pointed out the different states of shells buried in the strata, distinguishing between, first, the mere mould or impression; secondly, the cast or nucleus; and, thirdly, the remains of the shell itself. He had also the merit of being the first to point out, that some of the fossils had belonged to marine and some to terrestrial testacea.†

* Storia Naturale.

† Osserv. sugli Animali aquat. e terrest. 1626.

Steno, 1669.—But the most remarkable work of that period was published by Steno, a Dane, once professor of anatomy at Padua, and who afterwards resided many years at the court of the Grand Duke of Tuscany. His treatise bears the quaint title of 'De Solido intra Solidum naturaliter contento (1669),' by which the author intended to express, 'On Gems, Crystals, and organic Petrifactions inclosed within solid Rocks.' This work attests the priority of the Italian school in geological research; exemplifying at the same time the powerful obstacles opposed, in that age, to the general reception of enlarged views in the science. It was still a favourite dogma, that the fossil remains of shells and marine creatures were not of animal origin; an opinion adhered to by many from their extreme reluctance to believe, that the earth could have been inhabited by living beings before a great part of the existing mountains were formed. In reference to this controversy, Steno had dissected a shark recently taken from the Mediterranean, and had demonstrated that its teeth and bones were identical with many fossils found in Tuscany. He had also compared the shells discovered in the Italian strata with living species, pointed out their resemblance, and traced the various gradations from shells which had only lost their animal gluten, to those petrifactions in which there was a perfect substitution of stony matter. In his division of mineral masses, he insisted on the secondary origin of those deposits in which the spoils of animals or fragments of older rocks were inclosed. He distinguished between marine formations and those of a fluviatile character, the last containing reeds, grasses, or the trunks and branches of trees. He argued in favour of the original horizontality of sedimentary deposits, attributing their present inclined and vertical position sometimes to the escape of subterranean vapours heaving the crust of the earth from below upwards, and sometimes to the falling in of masses overlying subterranean cavities.

He declared that he had obtained proof that Tuscany must successively have acquired six distinct configurations, having been twice covered by water, twice laid dry with a level,

and twice with an irregular and uneven surface.* He displayed great anxiety to reconcile his new views with Scripture, for which purpose he pointed to certain rocks as having been formed before the existence of animals and plants : selecting unfortunately as examples certain formations of limestone and sandstone in his adopted country, now known to contain, though sparingly, the remains of animals and plants,—strata which do not even rank as the oldest part of our secondary series.

Scilla, 1670.—Scilla, a Sicilian painter, published, in 1670, a treatise, in Latin, on the fossils of Calabria, illustrated by good engravings. This work proves the continued ascendency of dogmas often refuted; for we find the wit and eloquence of the author chiefly directed against the obstinate incredulity of naturalists as to the organic nature of fossil shells. He quotes the remark of Cicero on the story that a stone in Chios had been cleft open, and presented the head of Paniscus in relief:—'I believe,' says Cicero, 'that the figure bore some resemblance to Paniscus, but not such that you would have deemed it sculptured by Scopas ; for chance never perfectly imitates the truth.' Like many eminent naturalists of his day, Scilla seems to give way to the popular persuasion, that all fossil shells were the effects and proofs of the Mosaic deluge.

Diluvial Theory.—The theologians who now entered the field in Italy, Germany, France, and England, were innumerable ; and henceforward, they who refused to subscribe to the position, that all marine organic remains were proofs of the Mosaic deluge, were exposed to the imputation of disbelieving the whole of the sacred writings. Scarcely any step had been made in approximating to sound theories since the time of Fracastoro, more than a hundred years having been lost, in writing down the dogma that organised fossils were mere sports of nature. An additional period of a century and a half was now destined to be consumed in exploding the hypothesis, that organised fossils had all been buried in the solid strata by Noah's flood. Never did a

* 'Sex itaque distinctas Etruriæ facies agnoscimus, dum bis fluida, bis plana, et sicca, bis aspera fuerit,' &c.

theoretical fallacy, in any branch of science, interfere more seriously with accurate observation and the systematic classification of facts. In recent times, we may attribute our rapid progress chiefly to the careful determination of the order of succession in mineral masses, by means of their different organic contents, and their regular superposition. But the old diluvialists were induced by their system to confound all the groups of strata together, referring all appearances to one cause and to one brief period, not to a variety of causes acting throughout a long succession of epochs. They saw the phenomena only, as they desired to see them, sometimes misrepresenting facts, and at other times deducing false conclusions from correct data. In short, a sketch of the progress of geology from the close of the seventeenth to the end of the eighteenth century is the history of a constant and violent struggle of new opinions against doctrines sanctioned by the implicit faith of many generations, and supposed to rest on scriptural authority.

Quirini, 1676.—Quirini, in 1676,* contended, in opposition to Scilla, that the diluvial waters could not have conveyed heavy bodies to the summit of mountains, since the agitation of the sea never, as Boyle had demonstrated, extended to great depths; and still less could the testacea, as some pretended, have lived in these diluvial waters; for 'the duration of the flood was brief, and *the heavy rains must have destroyed the saltness of the sea*!' The opinions of Boyle, alluded to by Quirini, were published a few years before, in a short article entitled 'On the Bottom of the Sea.' From observations collected from the divers of the pearl fishery, Boyle inferred that, when the waves were six or seven feet high above the surface of the water, there were no signs of agitation at the depth of fifteen fathoms; and that even during heavy gales of wind, the motion of the water was exceedingly diminished at the depth of twelve or fifteen feet. He had also learnt from some of his informants, that there were currents running in opposite directions at different depths.† He was the first writer who

* De Testaceis fossilibus Mus. Septaliani.

† Boyle's Works, vol. iii. p. 110. London, 1744.

ventured to maintain that the universality of the Mosaic cataclysm ought not to be insisted upon. As to the nature of petrified shells, he conceived that as earthy particles united in the sea to form the shells of mollusca, the same crystallising process might be effected on the land; and that, in the latter case, the germs of animals might have been disseminated through the substance of the rocks, and afterwards developed by virtue of humidity. Visionary as was this doctrine, it gained many proselytes even amongst the more sober reasoners of Italy and Germany; for it conceded that the position of fossil bodies could not be accounted for by the diluvial theory.

Plot—Lister, 1678.—In the meantime, the doctrine that fossil shells had never belonged to real animals maintained its ground in England, where the agitation of the question began at a much later period. Dr. Plot, in his 'Natural History of Oxfordshire' (1677), attributed to a 'plastic virtue latent in the earth' the origin of fossil shells and fishes; and Lister, to his accurate account of British shells, in 1678, added the fossil species under the appellation of *turbinated and bivalve stones.* 'Either,' said he, 'these were terriginous, or, if otherwise, the animals they so exactly represent *have become extinct.*' This writer appears to have been the first who was aware of the continuity over large districts of the principal groups of strata in the British series, and who proposed the construction of regular geological maps.*

Leibnitz, 1680.—The great mathematician Leibnitz published his 'Protogœa' in 1680. He imagined this planet to have been originally a burning luminous mass, which ever since its creation has been undergoing refrigeration. When the outer crust had cooled down sufficiently to allow the vapours to be condensed, they fell, and formed a universal ocean, covering the loftiest mountains, and investing the whole globe. The crust, as it consolidated from a state of fusion, assumed a vesicular and cavernous structure; and being rent in some places, allowed the water to rush into the

* See Conybeare and Phillips, 'Outlines of the Geology of England and Wales,' p. 12.

subterranean hollows, whereby the level of the primeval ocean was lowered. The breaking in of these vast caverns is supposed to have given rise to the dislocated and deranged position of the strata 'which Steno had described,' and the same disruptions communicated violent movements to the incumbent waters, whence great inundations ensued. The waters, after they had been thus agitated, deposited their sedimentary matter during intervals of quiescence, and hence the various stony and earthy strata. 'We may recognise, therefore,' says Leibnitz, 'a double origin of primitive masses, the one by refrigeration from igneous fusion, the other by consolidation from aqueous solution.' By the repetition of similar causes (the disruption of the crust and consequent floods), alternations of new strata were produced until at length these causes were reduced to a condition of quiescent equilibrium, and a more permanent state of things was established.*

Hooke, 1668.—The 'Posthumous Works of Robert Hooke, M.D.,' well known as a great mathematician and natural philosopher, appeared in 1705, containing 'A Discourse on Earthquakes,' which, we are informed by his editor, was written in 1688, but revised at subsequent periods. Hooke frequently refers to the best Italian and English authors who wrote before his time on geological subjects; but there are no passages in his works implying that he participated in the enlarged views of Steno and Lister, or of his contemporary, Woodward, in regard to the geographical extent of certain groups of strata. His treatise, however, is the most philosophical production of that age, in regard to the causes of former changes in the organic and inorganic kingdoms of nature.

'However trivial a thing,' he says, 'a rotten shell may appear to some, yet these monuments of nature are more certain tokens of antiquity than coins or medals, since the best of those may be counterfeited or made by art and design, as may also books, manuscripts, and inscriptions, as all the learned are now sufficiently satisfied has often been actually

* For an able analysis of the views of Leibnitz, in his Protogæa, see Mr. Conybeare's Report to the Brit. Assoc. on the Progress of Geological Science 1832.

practised,' &c.; 'and though it must be granted that it is very difficult to read them (the records of nature) and *to raise a chronology out of them*, and to state the intervals of the time wherein such or such catastrophes and mutations have happened, yet it is not impossible.'*

Respecting the extinction of species, Hooke was aware that the fossil ammonites, nautili, and many other shells and fossil skeletons found in England were of different species from any then known; but he doubted whether the species had become extinct, observing that the knowledge of naturalists of all the marine species, especially those inhabiting the deep sea, was very defective. In some parts of his writing, however, he leans to the opinion that species had been lost; and in speculating on this subject, he even suggests that there might be some connection between the disappearance of certain kinds of animals and plants, and the changes wrought by earthquakes in former ages. Some species, he observes, with great sagacity, are '*peculiar to certain places*, and not to be found elsewhere. If, then, such a place had been swallowed up, it is not improbable but that those animate beings may have been destroyed with it; and this may be true both of aërial and aquatic animals: for those animated bodies, whether vegetables or animals, which were naturally nourished or refreshed by the air, would be destroyed by the water,' &c.† Turtles, he adds, and such large ammonites as are found in Portland, seem to have been the productions of hotter countries; and it is necessary to suppose that England once lay under the sea within the torrid zone! To explain this and similar phenomena, he indulges in a variety of speculations concerning changes in the position of the axis of the earth's rotation, 'a shifting of the earth's centre of gravity, analogous to the revolutions of the magnetic pole,' &c. None of these conjectures, however, are proposed dogmatically, but rather in the hope of promoting fresh enquiries and experiments.

In opposition to the prejudices of his age, we find him arguing against the idea that nature had formed fossil bodies for no other end than to play the mimic in the mineral

* Posth. Works, Lecture, Feb. 29, 1688.

† Posth. Works, p. 327.

kingdom;'—maintaining that figured stones were 'really the several bodies they represent, or the mouldings of them petrified,' and 'not as some have imagined, "a lusus naturæ," sporting herself in the needless formation of useless beings.' * He explained, with considerable clearness, the different modes in which organic substances may become lapidified; and, among other illustrations, he mentions some silicified palm-wood brought from Africa, on which M. de la Hire had read a memoir to the Royal Academy of France (June 1692), wherein he had pointed out, not only the tubes running the length of the trunk, but the roots at one extremity. De la Hire, says Hooke, also treated of certain trees found petrified in the 'river that passes by Bakan, in the kingdom of *Ava*, and which has for the space of ten leagues the virtue of petrifying wood.' It is an interesting fact that the silicified wood of the Irawadi should have attracted attention nearly two hundred years ago. Remarkable discoveries have been made there in later times (1827) of fossil animals and vegetables, by Mr. Crawfurd and Dr. Wallich.†

It was objected to Hooke, that his doctrine of the extinction of species derogated from the wisdom and power of the Omnipotent Creator; but he answered, that, as individuals die, there may be some termination to the duration of a species; and his opinions, he declared, were not repugnant to Holy Writ: for the Scriptures taught that our system was degenerating, and tending to its final dissolution; 'and as, when that shall happen, all the species will be lost, why not some at one time and some at another?'‡

But his principal object was to account for the manner in which shells had been conveyed into the higher parts of 'the Alps, Apennines, and Pyrenean hills, and the interior of continents in general.' These and other appearances, he said, might have been brought about by earthquakes, 'which have turned plains into mountains, and mountains into plains, seas into land, and land into seas, made rivers where there

* Posth. Works, Lecture, Feb. 15, 1688.

† See Geol. Trans. vol. ii. part iii. p. 377, second series. De la Hire cities Father Duchatz in the second volume of 'Observations made in the Indies by the Jesuits.'

‡ Posth. Works, Lecture, May 29, 1689.

were none before, and swallowed up others that formerly were, &c. &c.; and which, since the creation of the world, have wrought many changes on the superficial parts of the earth, and have been the instruments of placing shells, bones, plants, fishes, and the like, in those places where, with much astonishment, we find them.'* This doctrine, it is true, had been laid down in terms almost equally explicit by Strabo, to explain the occurrence of fossil shells in the interior of continents, and to that geographer, and other writers of antiquity, Hooke frequently refers; but the revival and development of the system was an important step in the progress of modern science.

Hooke enumerated all the examples known to him of subterranean disturbance, from 'the sad catastrophe of Sodom and Gomorrah,' down to the Chilian earthquake of 1646. The elevating of the bottom of the sea, the sinking and submersion of the land, and most of the inequalities of the earth's surface, might, he said, be accounted for by the agency of these subterranean causes. He mentions that the coast near Naples *was raised during the eruption of Monte Nuovo*; and that, in 1591, land rose in the island of St. Michael, during an eruption: and although it would be more difficult, he says, to prove, he does not doubt but that there had been as many earthquakes in the parts of the earth under the ocean, as in the parts of the dry land; in confirmation of which, he mentions the immeasurable depth of the sea near some volcanos. To attest the extent of simultaneous subterranean movements, he refers to an earthquake in the West Indies, in the year 1690, where the space of earth raised, or 'struck upwards,' by the shock, exceeded, he affirms, the length of the Alps and Pyrenees.

Hooke's diluvial theory.—As Hooke declared the favourite hypothesis of the day, 'that marine fossil bodies were to be referred to Noah's flood,' to be wholly untenable, he appears to have felt himself called upon to substitute a diluvial theory of his own, and thus he became involved in countless difficulties and contradictions. 'During the great catastrophe,'

* Posth. Works, p. 312.

he said, 'there might have been a changing of that part which was before dry land into sea by sinking, and of that which was sea into dry land by raising, and marine bodies might have been buried in sediment beneath the ocean, in the interval between the creation and the deluge.'* Then follows a disquisition on the separation of the land from the waters, mentioned in Genesis; during which operation some places of the shell of the earth were forced outwards, and others pressed downwards or inwards, &c. His diluvial hypothesis very much resembled that of Steno, and was entirely opposed to the fundamental principles professed by him, that he would explain the former changes of the earth *in a more natural manner* than others had done. When, in despite of this declaration, he required a former 'crisis of nature,' and taught that earthquakes had become debilitated, and that the Alps, Andes, and other chains, had been lifted up in a few months, he was compelled to assume so rapid a rate of change, that his machinery appeared scarcely less extravagant than that of his most fanciful predecessors. For this reason, perhaps, his whole theory of earthquakes met with undeserved neglect.

Ray, 1692.—One of his contemporaries, the celebrated naturalist, Ray, participated in the same desire to explain geological phenomena by reference to causes less hypothetical than those usually resorted to.† In his essay on 'Chaos and Creation,' he proposed a system, agreeing in its outline, and in many of its details, with that of Hooke; but his knowledge of natural history enabled him to elucidate the subject with various original observations. Earthquakes, he suggested, might have been the second causes employed at the creation, in separating the land from the waters, and in gathering the waters together into one place. He mentions, like Hooke, the earthquake of 1646, which had violently shaken the Andes for some hundreds of leagues, and made many alterations therein. In assigning a cause for the general deluge, he

* Posth. Works, p. 410.

† Ray's Physico-theological Discourses were of somewhat later date than Hooke's great work on earthquakes. He speaks of Hooke as one 'whom for his learning and deep insight into the mysteries of nature he deservedly honoured.'—*On the Deluge*, chap. iv.

preferred a change in the earth's centre of gravity to the introduction of earthquakes. Some unknown cause, he said, might have forced the subterranean waters outwards, as was, perhaps indicated by 'the breaking up of the fountains of the great deep.'

Ray was one of the first of our writers who enlarged upon the effects of running water upon the land, and of the encroachment of the sea upon the shores. So important did he consider the agency of these causes, that he saw in them an indication of the tendency of our system to its final dissolution; and he wondered why the earth did not proceed more rapidly towards a general submersion beneath the sea, when so much matter was carried down by rivers, or undermined in the sea-cliffs. We perceive clearly from his writings, that the gradual decline of our system, and its future consummation by fire, was held to be as necessary an article of faith by the orthodox, as was the recent origin of our planet. His discourses, like those of Hooke, are highly interesting, as attesting the familiar association in the minds of philosophers, in the age of Newton, of questions in physics and divinity. Ray gave an unequivocal proof of the sincerity of his mind, by sacrificing his preferment in the Church, rather than take an oath against the Covenanters, which he could not reconcile with his conscience. His reputation, moreover, in the scientific world placed him high above the temptation of courting popularity, by pandering to the physico-theological taste of his age. It is, therefore, curious to meet with so many citations from the Christian fathers and prophets in his essays on physical science—to find him in one page proceeding, by the strict rules of induction, to explain the former changes of the globe, and in the next gravely entertaining the question, whether the sun and stars, and the whole heavens, shall be annihilated, together with the earth, at the era of the grand conflagration.

Woodward, 1695.—Among the contemporaries of Hooke and Ray, Woodward, a professor of medicine, had acquired the most extensive information respecting the geological structure of the crust of the earth. He had examined many parts of the British strata with minute attention; and his

systematic collection of specimens, bequeathed to the University of Cambridge, and still preserved there as arranged by him, shows how far he had advanced in ascertaining the order of superposition. From the great number of facts collected by him, we might have expected his theoretical views to be more sound and enlarged than those of his contemporaries; but in his anxiety to accommodate all observed phenomena to the scriptural account of the Creation and Deluge, he arrived at most erroneous results. He conceived 'the whole terrestrial globe to have been taken to pieces and dissolved at the flood, and the strata to have settled down from this promiscuous mass as any earthy sediment from a fluid.'* In corroboration of these views he insisted upon the fact, that 'marine bodies are lodged in the strata according to the order of their gravity, the heavier shells in stone, the lighter in chalk, and so of the rest.'† Ray immediately exposed the unfounded nature of this assertion, remarking truly that fossil bodies 'are often mingled, heavy with light, in the same stratum;' and he even went so far as to say, that Woodward 'must have invented the phenomena for the sake of confirming his bold and strange hypothesis.'‡

Burnet, 1680–1690.—At the same time Burnet published his 'Theory of the Earth.'§ The title is most characteristic of the age,—'The Sacred Theory of the Earth; containing an Account of the Original of the Earth, and of all the general Changes which it hath already undergone, or is to undergo, till the Consummation of all Things.' Even Milton had scarcely ventured in his poem to indulge his imagination so freely in painting scenes of the Creation and Deluge, Paradise and Chaos. He explained why the primeval earth enjoyed a perpetual spring before the flood! showed how the crust of the globe was fissured by 'the sun's rays,' so that it burst, and thus the diluvial waters were let loose from a supposed central abyss. Not satisfied with these themes, he derived from the books of the inspired writers, and even from heathen authorities, prophetic views of the

* Essay towards a Natural History of the Earth, 1695. Preface.

† Ibid.

‡ Consequences of the Deluge, p. 165.

§ First published in Latin between the years 1680 and 1690.

future revolutions of the globe, gave a most terrific description of the general conflagration, and proved that a new heaven and a new earth will rise out of a *second chaos*—after which will follow the blessed millennium.

The reader should be informed, that, according to the opinion of many respectable writers of that age, there was good scriptural ground for presuming that the garden bestowed upon our first parents was not on the earth itself, but above the clouds, in the middle region between our planet and the moon. Burnet approaches with becoming gravity the discussion of so important a topic. He was willing to concede that the geographical position of Paradise was not in Mesopotamia, yet he maintained that it was upon the earth, and in the southern hemisphere, near the equinoctial line. Butler selected this conceit as a fair mark for his satire, when, amongst the numerous accomplishments of Hudibras, he says,—

> He knew the seat of Paradise,
> Could tell in what degree it lies;
> And, as he was disposed, could prove it
> Below the moon, or else above it.

Yet the same monarch, who is said never to have slept without Butler's poem under his pillow, was so great an admirer and patron of Burnet's book, that he ordered it to be translated from the Latin into English. The style of the 'Sacred Theory' was eloquent, and the book displayed powers of invention of no ordinary stamp. It was, in fact, a fine historical romance, as Buffon afterwards declared: but it was treated as a work of profound science in the time of its author, and was panegyrised by Addison in a Latin ode, while Steele praised it in the 'Spectator.'

Whiston, 1696.—Another production of the same school, and equally characteristic of the time, was that of Whiston, entitled, 'A New Theory of the Earth; wherein the Creation of the World in Six Days, the Universal Deluge, and the General Conflagration, as laid down in the Holy Scriptures, are shown to be perfectly agreeable to Reason and Philosophy.' He was at first a follower of Burnet; but his faith in the infallibility of that writer was shaken by the declared

opinion of Newton, that there was every presumption in astronomy against any former change in the inclination of the earth's axis. This was a leading dogma in Burnet's system, though not original, for it was borrowed from an Italian, Alessandro degli Alessandri, who had suggested it in the beginning of the fifteenth century, to account for the former occupation of the present continents by the sea. La Place has since strengthened the arguments of Newton, against the probability of any former revolution of this kind.

The remarkable comet of 1680 was fresh in the memory of every one when Whiston first began his cosmological studies; and the principal novelty of his speculations consisted in attributing the deluge to the near approach to the earth of one of these erratic bodies, and the condensation of the vapour of its tail into water. Having ascribed an increase of the waters to this source, he adopted Woodward's theory, supposing all stratified deposits to have resulted from the 'chaotic sediment of the flood.' Whiston was one of the first who ventured to propose that the text of Genesis should be interpreted differently from its ordinary acceptation, so that the doctrine of the earth having existed long previous to the creation of man might be no longer regarded as unorthodox. He had the art to throw an air of plausibility over the most improbable parts of his theory, and seemed to be proceeding in the most sober manner, and, by the aid of mathematical demonstration, to the establishment of his various propositions. Locke pronounced a panegyric on his theory, commending him for having explained so many wonderful and before inexplicable things. His book, as well as Burnet's, was attacked and refuted by Keill.*

Hutchinson, 1724.—John Hutchinson, who had been employed by Woodward in making his collection of fossils, published afterwards, in 1724, the first part of his 'Moses's Principia,' wherein he ridiculed Woodward's hypothesis. He and his numerous followers were accustomed to declaim loudly against human learning; and they maintained that the Hebrew Scriptures, when rightly translated, comprised a

* An Examination of Dr. Burnet's Theory, &c. 2d ed. 1734.

perfect system of natural philosophy, for which reason they objected to the Newtonian theory of gravitation.

Celsius.—Andrea Celsius, the Swedish astronomer, published about this time his remarks on the gradual diminution and sinking of the waters in the Baltic, to which I shall have occasion to advert more particularly in the sequel (Ch. 31).

Scheuchzer, 1708.—In Germany, in the meantime, Scheuchzer published his 'Complaint and Vindication of the Fishes' (1708), 'Piscium Querelæ et Vindiciæ,' a work of zoological merit, in which he gave some good plates and descriptions of fossil fish. Among other conclusions he laboured to prove that the earth had been remodelled at the deluge. Pluche, also, in 1732, wrote to the same effect; while Holbach, in 1753, after considering the various attempts to refer all the ancient formations to the flood of Noah, exposed the inadequacy of this cause.

Italian Geologists—Vallisneri, 1721.—I return with pleasure to the geologists of Italy, who preceded, as has been already shown, the naturalists of other countries in their investigations into the ancient history of the earth, and who still maintained a decided pre-eminence. They refuted and ridiculed the physico-theological systems of Burnet, Whiston, and Woodward; while Vallisneri,* in his comments on the Woodwardian theory, remarked how much the interests of religion, as well as those of sound philosophy, had suffered by perpetually mixing up the sacred writings with questions in physical science. The works of this author were rich in original observations. He attempted the first general sketch of the marine deposits of Italy, their geographical extent, and most characteristic organic remains. In his treatise 'On the Origin of Springs,' he explained their dependence on the order, and often on the dislocations, of the strata, and reasoned philosophically against the opinions of those who regarded the disordered state of the earth's crust as exhibiting signs of the wrath of God for the sins of man. He found himself under the necessity of contending, in his preliminary chapter, against St. Jerome, and four other principal

* Dei Corpi Marini. Lettere critiche, &c. 1721.

interpreters of Scripture, besides several professors of divinity, 'that springs did not flow by subterranean siphons and cavities from the sea upwards, losing their saltness in the passage,' for this theory had been made to rest on the infallible testimony of Holy Writ.

Although reluctant to generalise on the rich materials accumulated in his travels, Vallisneri had been so much struck with the remarkable continuity of the more recent marine strata, from one end of Italy to the other, that he came to the conclusion that the ocean formerly extended over the whole earth, and after abiding there for a long time, had gradually subsided. This opinion, however untenable, was a great step beyond Woodward's diluvian hypothesis, against which Vallisneri, and after him all the Tuscan geologists, uniformly contended, while it was warmly supported by the members of the Institute of Bologna.*

Among others of that day, Spada, a priest of Grezzana, in 1737, wrote to prove that the petrified marine bodies near Verona were not diluvian.† Mattani drew a similar inference from the shells of Volterra and other places: while Costantini, on the other hand, whose observations on the valley of the Brenta and other districts were not without value, undertook to vindicate the truth of the deluge, as also to prove that Italy had been peopled by the descendants of Japhet.‡

Moro, 1740.—Lazzaro Moro, in his work (published in 1740) 'On the Marine Bodies which are found in the Mountains,'§ attempted to apply the theory of earthquakes, and changes of level in the earth's crust, as expounded by Strabo, Pliny, and other ancient authors, with whom he was familiar, to the geological phenomena described by Vallisneri.‖ His attention was awakened to the elevating power of subterranean forces by a remarkable phenomenon

* Brocchi, p. 28.

† Ibid. p. 33.

‡ Ibid.

§ Sui Crostacei ed altri Corpi Marini che si trovano sui Monti.

‖ Moro does not cite the works of Hooke and Ray: and although so many of his views were in accordance with theirs, he was probably ignorant of their writings, for they had not been translated. As he always refers to the Latin edition of Burnet, and a French translation of Woodward, we may presume that he did not read English.

which happened in his own time, and which had also been noticed by Vallisneri in his letters. A new island rose in 1707 from deep water in the Gulf of Santorin in the Mediterranean, during continued shocks of an earthquake, and, increasing rapidly in size, grew in less than a month to be half a mile in circumference, and about twenty-five feet above high-water mark.* It was soon afterwards covered by volcanic ejections, but, when first examined, it was found to be a white rock, bearing on its surface living oysters and crustacea. In order to ridicule the various theories then in vogue, Moro ingeniously supposes the arrival on this new island of a party of naturalists ignorant of its recent origin. One immediately points to the marine shells, as proofs of the universal deluge; another argues that they demonstrate the former residence of the sea upon the mountains; a third dismisses them as mere *sports of nature*; while a fourth affirms, that they were born and nourished within the rock in ancient caverns, into which salt water had been raised in the shape of vapour by the action of subterranean heat.

Moro pointed with great judgment to the *faults* and dislocations of the strata described by Vallisneri, in the Alps and other chains, in confirmation of his doctrine, that the continents had been heaved up by subterranean movements. He objected, on solid grounds, to the hypothesis of Burnet and of Woodward; yet he ventured so far to disregard the protest of Vallisneri, as to undertake the adaptation of every part of his own system to the Mosaic account of the creation. On the third day, he said, the globe was everywhere covered to the same depth by fresh water; and when it pleased the Supreme Being that the dry land should appear, volcanic explosions broke up the smooth and regular surface of the earth composed of primary rocks. These rose in mountain masses above the waves, and allowed melted metals and salts to ascend through fissures. The sea gradually acquired its saltness from volcanic exhalations, and, while it became more circumscribed in area, increased in depth. Sand and ashes ejected by volcanos

* For an account of a similar eruption in the Gulf of Santorin in 1866, see Principles of Geology, vol. ii. p. 69, 10th ed. 1868.

were regularly disposed along the bottom of the ocean, and formed the secondary strata, which in their turn were lifted up by earthquakes. We need not follow this author in tracing the progress of the creation of vegetables and animals on the other days of creation; but, upon the whole, it may be remarked, that few of the old cosmological theories had been conceived with so little violation of known analogies.

Generelli's illustrations of Moro, 1749.—The style of Moro was extremely prolix, and, like Hutton, who, at a later period, advanced many of the same views, he stood in need of an illustrator. The Scotch geologist was hardly more fortunate in the advocacy of Playfair, than was Moro in numbering amongst his admirers Cirillo Generelli, who, nine years afterwards, delivered at a sitting of Academicians at Cremona a spirited exposition of his theory. This learned Carmelite friar does not pretend to have been an original observer, but he had studied sufficiently to enable him to confirm the opinions of Moro by arguments from other writers; and the selection of the doctrines then best established is so judicious, that a brief abstract of them cannot fail to be acceptable, as illustrating the state of geology in Europe, and in Italy in particular, before the middle of the last century.

The bowels of the earth, says he, have carefully preserved the memorials of past events, and this truth the marine productions so frequent in the hills attest. From the reflections of Lazzaro Moro, we may assure ourselves that these are the effects of earthquakes in past times, which have changed vast spaces of sea into terra firma, and inhabited lands into seas. In this more than in any other department of physics, are observations and experiments indispensable, and we must diligently consider facts. The land is known, wherever we make excavations, to be composed of different strata or soils placed one above the other, some of sand, some of rock, some of chalk, others of marl, coal, pumice, gypsum, lime, and the rest. These ingredients are sometimes pure, and sometimes confusedly intermixed. Within are often imprisoned different marine fishes, like dried

mummies, and more frequently shells, crustacea, corals, plants, &c., not only in Italy, but in France, Germany, England, Africa, Asia, and America; sometimes in the lowest, sometimes in the loftiest beds of the earth, some upon the mountains, some in deep mines, others near the sea, and others hundreds of miles distant from it. Woodward conjectured that these marine bodies might be found everywhere; but there are rocks in which none of them occur, as is sufficiently attested by Vallisneri and Marsilli. The remains of fossil animals consist chiefly of their more solid parts, and the most rocky strata must have been soft when such exuviæ were enclosed in them. Vegetable productions are found in different states of maturity, indicating that they were imbedded in different seasons. Elephants, elks, and other terrestrial quadrupeds, have been found in England and elsewhere, in superficial strata, never covered by the sea. Alternations are rare, yet not without example, of marine strata, with those which contain marshy and terrestrial productions. Marine animals are arranged in the subterraneous beds with admirable order, in distinct groups, oysters here, dentalia or corals there, &c., as now, according to Marsilli,* on the shores of the Adriatic. We must abandon the doctrine, once so popular, which denies that organised fossils were derived from living beings, and we cannot account for their present position by the ancient theory of Strabo, nor by that of Leibnitz, nor by the universal deluge, as explained by Woodward and others: 'nor is it reasonable to call the Deity capriciously upon the stage, and to make him work miracles for the sake of confirming our preconceived hypothesis.'—'I hold in utter abomination, most learned Academicians! those systems which are built with their foundations in the air, and cannot be propped up without a miracle; and I undertake, with the assistance of Moro, to explain to you how these marine animals were transported into the mountains by natural causes.'†

A brief abstract then follows of Moro's theory, by which,

* Saggio fisico intorno alla Storia del Mare, part i. p. 24.

† 'Abbomino al sommo qualsivoglia sistema, che sia di pianta fabbricato in aria; massime quando è tale, che non possa sostenersi senza un miracolo,' &c. —De' Crostacei e di altre Produz. del Mare, &c. 1749.

says Generelli, we may explain all the phenomena, as Vallisneri so ardently desired, 'without violence, without fictions, without hypothesis, without miracles'—'Senza violenze, senza finzioni, senza supposti, senza miracoli.' The Carmelite then proceeds to struggle against an obvious objection to Moro's system, considered as a method of explaining the revolutions of the earth, *naturally*. If earthquakes have been the agents of such mighty changes, how does it happen that their effects since the times of history have been so inconsiderable? This same difficulty had, as we have seen, presented itself to Hooke, half a century before, and forced him to resort to a former 'crisis of nature:' but Generelli defended his position by showing how numerous were the accounts of eruptions and earthquakes, of new islands, and of elevations and subsidences of land, and yet how much greater a number of like events must have been unattested and unrecorded during the last six thousand years. He also appealed to Vallisneri as an authority to prove that the mineral masses containing shells bore, upon the whole, but a small proportion to those rocks which were destitute of organic remains; and the latter, says the learned monk, might have been created as they now exist, *in the beginning*.

Generelli then describes the continual waste of mountains and continents, by the action of rivers and torrents, and concludes with these eloquent and original observations:—'Is it possible that this waste should have continued for six thousand, and *perhaps* a greater number of years, and that the mountains should remain so great, unless their ruins have been repaired? Is it credible that the Author of Nature should have founded the world upon such laws, as that the dry land should for ever be growing smaller, and at last become wholly submerged beneath the waters? Is it credible that, amid so many created things, the mountains alone should daily diminish in number and bulk, without there being any repair of their losses? This would be contrary to that order of Providence which is seen to reign in all other things in the universe. Wherefore I deem it just to conclude, that the same cause which, in the beginning of time, raised mountains from the abyss, has down

to the present day continued to produce others, in order to restore from time to time the losses of all such as sink down in different places, or are rent asunder, or in other ways suffer disintegration. If this be admitted, we can easily understand why there should now be found upon many mountains so great a number of crustacea and other marine animals.'

In the above extract, I have not merely enumerated the opinions and facts which are confirmed by recent observation, suppressing all that has since proved to be erroneous, but have given a faithful abridgment of the entire treatise, with the omission only of Moro's hypothesis, which Generelli adopted, with all its faults and excellences. The reader will therefore remark, that although this admirable essay embraces so large a portion of the principal objects of geological research, it makes no allusion to the extinction of certain classes of animals; and it is evident that no opinions on this head had, at that time, gained a firm footing in Italy. That Lister and other English naturalists should long before have declared in favour of the loss of species, while Scilla and most of his countrymen hesitated, was perhaps natural, since the Italian museums were filled with fossil shells belonging to species of which a great portion did actually exist in the Mediterranean; whereas the English collectors could obtain no recent species from such of their own strata as were then explored.

The weakest point in Moro's system consisted in deriving *all* the stratified rocks from volcanic ejections; an absurdity which his opponents took care to expose, especially Vito Amici.* Moro seems to have been misled by his anxious desire to represent the formation of secondary rocks as having occupied an extremely short period, while at the same time he wished to employ known agents in nature. To imagine torrents, rivers, currents, partial floods, and all the operations of moving water, to have gone on exerting an energy many thousand times greater than at present, would have appeared preposterous and incredible, and would have required a

* Sui Testacei della Sicilia.

hundred violent hypotheses; but we are so unacquainted with the true sources of subterranean disturbances, that their former violence may in theory be multiplied indefinitely, without its being possible to prove the same manifest contradiction or absurdity in the conjecture. For this reason, perhaps, Moro preferred to derive the materials of the strata from volcanic ejections, rather than from transportation by running water.

Marsilli.—Marsilli, whose work is alluded to by Generelli, had been prompted to institute enquiries into the bed of the Adriatic, by discovering, in the territory of Parma, (what Spada had observed near Verona, and Schiavo in Sicily,) that fossil shells were not scattered through the rocks at random, but disposed in regular order, according to certain genera and species.

Vitaliano Donati, 1750.—With a view of throwing further light upon these questions, Donati, in 1750, undertook a more extensive investigation of the Adriatic, and discovered, by numerous soundings, that deposits of sand, marl, and tufaceous incrustations, most strictly analogous to those of the Subapennine hills, were in the act of accumulating there. He ascertained that there were no shells in some of the submarine tracts, while in other places they lived together in families, particularly the genera Arca, Pecten, Venus, Murex, and some others. He also states that in divers localities he found a mass composed of corals, shells, and crustaceous bodies of different species, confusedly blended with earth, sand, and gravel. At the depth of a foot or more, the organic substances were entirely petrified and reduced to marble; at less than a foot from the surface, they approached nearer to their natural state; while at the surface they were alive, or, if dead, in a good state of preservation.

Baldassari.—A contemporary naturalist, Baldassari, had shown that the organic remains in the tertiary marls of the Siennese territory were grouped in families, in a manner precisely similar to that above alluded to by Donati.

Buffon, 1749.—Buffon first made known his theoretical views concerning the former changes of the earth, in his 'Natural History,' published in 1749. He adopted the theory

of an original volcanic nucleus, together with the universal ocean of Leibnitz. By this aqueous envelope the highest mountains were once covered. Marine currents then acted violently, and formed horizontal strata, by washing away solid matter in some parts, and depositing it in others; they also excavated deep submarine valleys. The level of the ocean was then depressed by the entrance of a part of its waters into subterranean caverns, and thus some land was left dry. Buffon seems not to have profited, like Leibnitz and Moro, by the observations of Steno, or he could not have imagined that the strata were generally horizontal, and that those which contained organic remains had never been disturbed since the era of their formation. He was conscious of the great power annually exerted by rivers and marine currents in transporting earthy materials to lower levels, and he even contemplated the period when they would destroy all the present continents. Although in geology he was not an original observer, his genius enabled him to render his hypothesis attractive; and by the eloquence of his style, and the boldness of his speculations, he awakened curiosity, and provoked a spirit of enquiry among his countrymen.

Soon after the publication of his 'Natural History,' in which was included his 'Theory of the Earth,' he received an official letter (dated January 1751) from the Sorbonne, or Faculty of Theology in Paris, informing him that fourteen propositions in his works 'were reprehensible, and contrary to the creed of the church.' The first of these obnoxious passages, and the only one relating to geology, was as follows:—'The waters of the sea have produced the mountains and valleys of the land—the waters of the heavens, reducing all to a level, will at last deliver the whole land over to the sea, and the sea successively prevailing over the land, will leave dry new continents like those which we inhabit.' Buffon was invited by the College, in very courteous terms, to send in an explanation, or rather a recantation of his unorthodox opinions. To this he submitted; and a general assembly of the Faculty having approved of his 'Declaration,' he was required to publish it in his next work. The document begins with these words:—'I declare that I

had no intention to contradict the text of Scripture; that I believe most firmly all therein related about the creation, both as to order of time and matter of fact; *I abandon everything in my book respecting the formation of the earth,* and, generally, all which may be contrary to the narration of Moses.'*

The grand principle which Buffon was called upon to renounce was simply this,—'that the present mountains and valleys of the earth are due to secondary causes, and that the same causes will in time destroy all the continents, hills, and valleys, and reproduce others like them.' Now, whatever may be the defects of many of his views, it is no longer controverted that the present continents are of secondary origin. The doctrine is as firmly established as the earth's rotation on its axis; and that the land now elevated above the level of the sea will not endure for ever, is an opinion which gains ground daily, in proportion as we enlarge our experience of the changes now in progress.

Targioni, 1751.—Targioni, in his voluminous 'Travels in Tuscany, 1751 and 1754,' laboured to fill up the sketch of the geology of that region left by Steno sixty years before. Notwithstanding a want of arrangement and condensation in his memoirs, they contained a rich store of faithful observations. He has not indulged in many general views, but in regard to the origin of valleys, he was opposed to the theory of Buffon, who attributed them principally to submarine currents. The Tuscan naturalist laboured to show that both the larger and smaller valleys of the Apennines were excavated by rivers and floods, caused by the bursting of the barriers of lakes, after the retreat of the ocean. He also maintained that the elephants and other quadrupeds, so frequent in the lacustrine and alluvial deposits of Italy, had inhabited that peninsula; and had not been transported thither, as some had conceived, by Hannibal or the Romans, nor by what they were pleased to term 'a catastrophe of nature.'

Lehman, 1756.—In the year 1756 the treatise of Lehman,

* Hist. Nat. tom. v. éd. de l'Imp. Royale. Paris, 1769.

a German mineralogist, and director of the Prussian mines, appeared, who divided mountains into three classes: the first, those formed with the world, and prior to the creation of animals, and which contained no fragments of other rocks; the second class, those which resulted from the partial destruction of the primary rocks by a general revolution; and a third class, resulting from local revolutions, and in part from the deluge of Noah.

A French translation of this work appeared in 1759, in the preface of which, the translator displays very enlightened views respecting the operations of earthquakes, as well as of aqueous causes.*

Gesner, 1758.—In this year Gesner, the botanist of Zurich, published an excellent treatise on petrifactions, and the changes of the earth which they testify.† After a detailed enumeration of the various classes of fossils of the animal and vegetable kingdoms, and remarks on the different states in which they are found petrified, he considers the geological phenomena connected with them; observing, that some, like those of Œningen, resembled the testacea, fish, and plants indigenous in the neighbouring region; ‡ while some, such as ammonites, gryphites, belemnites, and other shells, are either of unknown species, or found only in the Indian or other distant seas. In order to elucidate the structure of the earth, he gives sections, from Verenius, Buffon, and others, obtained in digging wells; distinguishes between horizontal and inclined strata; and, in speculating on the causes of these appearances, mentions Donati's examination of the bed of the Adriatic; the filling up of lakes and seas by sediment; the imbedding of shells, now in progress; and many known effects of earthquakes, such as the sinking down of districts, or the heaving up of the bed of the sea, so as to form new islands, and lay dry strata containing petrifactions. The ocean, he says, deserts its shores in many countries, as on the borders of the Baltic; but the rate of recession has been so slow in the last 2,000 years, that to allow the Apennines,

* Essai d'une Hist. nat. des Couches de la Terre. 1759.

† John Gesner published at Leyden, in Latin.

‡ Part ii. chap. 9.

whose summits are filled with marine shells, to emerge to their present height, would have required about 80,000 years,—a lapse of time ten times greater, or more, than the age of the universe. We must therefore refer the phenomenon to the command of the Deity, related by Moses, that 'the waters should be gathered together in one place, and the dry land appear.' Gesner adopted the views of Leibnitz, to account for the retreat of the primeval ocean: his essay displays much erudition; and the opinions of preceding writers of Italy, Germany, and England, are commented upon with fairness and discrimination.

Arduino, 1759.—In the year following, Arduino,* in his memoirs on the mountains of Padua, Vicenza, and Verona, deduced, from original observations, the distinction of rocks into primary, secondary, and tertiary, and showed that in those districts there had been a succession of submarine volcanic eruptions.

Michell, 1760.—In the following year (1760) the Rev. John Michell, Woodwardian Professor of Mineralogy at Cambridge, published in the Philosophical Transactions, an Essay on the Cause and Phenomena of Earthquakes.† His attention had been drawn to this subject by the great earthquake of Lisbon in 1755. He advanced many original and philosophical views respecting the propagation of subterranean movements, and the caverns and fissures wherein steam might be generated. In order to point out the application of his theory to the structure of the globe, he was led to describe the arrangement and disturbance of the strata, their usual horizontality in low countries, and their contortions and fractured state in the neighbourhood of mountain chains. He also explained, with surprising accuracy, the relations of the central ridges of older rocks to the 'long narrow slips of earth, stones, and minerals,' which are parallel to these ridges. In his generalisations, derived in great part from his own observations on the geological structure of Yorkshire, he anticipated many of the views

* Giornale de' Criselini. 1759.

† See a Sketch of the History of English Geology, by Dr. Fitton, in Edinb. Rev. Feb. 1818, re-edited Lond. and Edinb. Phil. Mag. vol. i. and ii. 1832–33.

more fully developed by later naturalists. Some of Michell's observations anticipate in so remarkable a manner the theories established forty years afterwards, that his writings would probably have formed an era in the science, if his researches had been uninterrupted. He held, however, his professorship only eight years, when his career was suddenly cut short by preferment to a benefice. From that time he appears to have been engaged in his clerical duties, and to have entirely discontinued his scientific pursuits.*

Catcott, 1761.—Michell's papers were entirely free from all physico-theological disquisitions, but some of his contemporaries were still earnestly engaged in defending or impugning the Woodwardian hypothesis. We find many of these writings referred to by Catcott, a Hutchinsonian, who published a 'Treatise on the Deluge' in 1761. He laboured particularly to refute an explanation offered by his contemporary, Bishop Clayton, of the Mosaic writings. That prelate had declared that the deluge 'could not be literally true, save in respect to that part where Noah lived before the flood.' Catcott insisted on the universality of the deluge, and referred to traditions of inundations mentioned by ancient writers, or by travellers, in the East Indies, China, South America, and other countries. This part of his book is valuable, although it is not easy to see what bearing the traditions have, if admitted to be authentic, on the Bishop's argument, since no evidence is adduced to prove that the catastrophes were contemporaneous events, while some of them are expressly represented by ancient authors to have occurred in succession.

Fortis—Odoardi, 1761.—The doctrines of Arduino, above adverted to, were afterwards confirmed by Fortis and Desmarest, in their travels in the same country; and they, as well as Baldassari, laboured to complete the history of the

* The abrupt suspension of Michell's scientific career exemplified the disadvantageous working of a system in full force at Oxford and Cambridge in the last century, where the chairs of mathematics, natural philosophy, chemistry, botany, astronomy, geology, mineralogy, and others, being frequently filled by clergymen, the reward of success disqualified them, if they conscientiously discharged their new duties, from farther advancing the cause of science, and that, too, at the moment when their labours would naturally bear the richest fruits.

Subapennine strata. In the work of Odoardi,* there was also a clear argument in favour of the distinct ages of the older Apennine strata, and the Subapennine formations of more recent origin. He pointed out that the strata of these two groups were *unconformable*, and must have been the deposits of different seas at distant periods of time.

Raspe, 1763.—A history of the new islands by Raspe, an Hanoverian, appeared in 1763, in Latin.† In this work, all the authentic accounts of earthquakes which had produced permanent changes on the solid parts of the earth were collected together and examined with judicious criticism. The best systems which had been proposed concerning the ancient history of the globe, both by ancient and modern writers, are reviewed; and the merits and defects of the doctrines of Hooke, Ray, Moro, Buffon, and others, fairly estimated. Great admiration is expressed for the hypothesis of Hooke, and his explanation of the origin of the strata is shown to have been more correct than Moro's, while their theory of the effects of earthquakes was the same. Raspe had not seen Michell's memoirs, and his views concerning the geological structure of the earth were perhaps less enlarged; yet he was able to add many additional arguments in favour of Hooke's theory, and to render it, as he said, a nearer approach to what Hooke would have written had he lived in later times. As to the periods wherein all the earthquakes happened, to which we owe the elevation of various parts of our continents and islands, Raspe says he pretends not to assign their duration, still less to defend Hooke's suggestion, that the convulsions almost all took place during the deluge of Noah. He adverts to the apparent indications of the former tropical heat of the climate of Europe, and the changes in the species of animals and plants, as among the most obscure and difficult problems in geology. In regard to the islands raised from the sea, within the times of history or tradition, he declares that some of them were

* Sui Corpi Marini del Feltrino. 1761.

† De Novis e Mari Natis Insulis. Raspe was also the editor of the 'Philosophical Works of Leibnitz. Amst. et Leipzig, 1765;' also author of 'Tassie's Gems,' and 'Baron Munchausen's Travels.'

composed of strata containing organic remains, and that they were not, as Buffon had asserted, made of mere volcanic matter. His work concludes with an eloquent exhortation to naturalists to examine the isles which rose, in 1707, in the Grecian Archipelago, and, in 1720, in the Azores, and not to neglect such splendid opportunities of studying nature 'in the act of parturition.' That Hooke's writings should have been neglected for more than half a century, was matter of astonishment to Raspe; but it is still more wonderful that his own luminous exposition of that theory should, for more than another half-century, have excited so little interest.

Fuchsel, 1762–1773.—Fuchsel, a German physician, published, in 1762, a geological description of the country between the Thuringerwald and the Hartz, and a memoir on the environs of Rudolstadt;* and afterwards, in 1773, a theoretical work on the ancient history of the earth and of man.† He had evidently advanced considerably beyond his predecessor Lehman, and was aware of the distinctness, both as to position and fossil contents, of several groups of strata of different ages, corresponding to the secondary formations now recognised by geologists in various parts of Germany. He supposed the European continents to have remained covered by the sea until the formation of the marine strata called in Germany 'muschelkalk,' at the same time that the terrestial plants of many European deposits, attested the existence of dry land which bordered the ancient sea; land which, therefore, must have occupied the place of the present ocean. This pre-existing continent had been *gradually* swallowed up by the sea, different parts having subsided in succession into subterranean caverns. All the sedimentary strata were originally horizontal, and their present state of derangement must be referred to subsequent oscillations of the ground.

As there were plants and animals in the ancient periods, so also there must have been men, but they did not all

* Acta Academiæ Electoralis Moguntinæ, vol. ii. Erfurt.

† This account of Fuchsel is derived from an excellent analysis of his memoirs by M. Keferstein. Journ. de Géologie, tom. ii. Oct. 1830.

descend from one pair, but were created at various points on the earth's surface; and the number of these distinct birth-places was as great as are the original languages of nations.

In the writings of Fuchsel we see a strong desire manifested to explain geological phenomena as far as possible by reference to the agency of known causes; and although some of his speculations were fanciful, his views coincide much more nearly with those now generally adopted, than the theories afterwards promulgated by Werner and his followers.

Brander, 1766.—Gustavus Brander published, in 1766, his 'Fossilia Hantoniensia,' containing excellent figures of fossil shells from the more modern (or Eocene) marine strata of Hampshire. 'Various opinions,' he says in the preface, 'had been entertained concerning the time when and how these bodies became deposited. Some there are who conceive that it might have been effected in a wonderful length of time by a gradual changing and shifting of the sea,' &c. But the most common cause assigned is that of 'the deluge.' This conjecture, he says, even if the universality of the flood be not called in question, is purely hypothetical. In his opinion, fossil animals and testacea were, for the most part, of unknown species; and of such as were known, the living analogues now belonged to southern latitudes.

Soldani, 1780.—Soldani applied successfully his knowledge of zoology to illustrate the history of stratified masses. He explained that microscopic testacea and zoophytes inhabited the depths of the Mediterranean; and that the fossil species were, in like manner, found in those deposits wherein the fineness of their particles, and the absence of pebbles, implied that they were accumulated in a deep sea, or far from shore. This author first remarked the alternation of marine and freshwater strata in the Paris basin.*

Fortis—Testa, 1793.—A lively controversy arose between Fortis and another Italian naturalist, Testa, concerning the fish of Monte Bolca, in 1793. Their letters,† written with great spirit and elegance, show that they were aware that a

* Saggio orittografico, &c. 1780, and other Works.

† Lett. sui Pesci Fossili di Bolca. Milan, 1793.

large proportion of the Subapennine shells were identical with living species, and some of them with species now living in the torrid zone. Fortis proposed a somewhat fanciful conjecture, that when the volcanos of the Vicentin were burning, the waters of the Adriatic had a higher temperature; and in this manner, he said, the shells of warmer regions may once have peopled their own seas. But Testa was disposed to think that these species of testacea were still common to their own and to equatorial seas: for many, he said, once supposed to be confined to hotter regions, had been afterwards discovered in the Mediterranean.

Cortesi—Spallanzani—Wallerius—Whitehurst, 1775–1798.—While these Italian naturalists, together with Cortesi and Spallanzani, were busily engaged in pointing out the analogy between the deposits of modern and ancient seas, and the habits and arrangements of their organic inhabitants, and while some progress was making, in the same country, in investigating the ancient and modern volcanic rocks, some of the most original observers among the English and German writers, Whitehurst* and Wallerius, were wasting their strength in contending, according to the old Woodwardian hypothesis, that all the strata were formed by Noah's deluge. But Whitehurst's description of the rocks of Derbyshire was most faithful; and he atoned for false theoretical views, by providing data for their refutation.

Pallas—Saussure, 1793-1799.—Towards the close of the eighteenth century, the idea of dividing the mineral masses on our globe into separate groups, and studying their relations, began to be generally diffused. Pallas and Saussure were among the most celebrated whose labours contributed to this end. After an attentive examination of the two great mountain-chains of Siberia, Pallas announced the result, that the granite rocks were in the middle, the schistose at their sides, and the limestones again on the outside of these; and this he conceived would prove a general law in the formation of all chains composed chiefly of primary rocks.†

In his 'Travels in Russia,' in 1793 and 1794, he made

* Inquiry into the Original State and Formation of the Earth. 1778.

† Observ. on the Formation of Mountains. Act. Pétrop. ann. 1778, part. i.

many geological observations on the recent strata near the Wolga and the Caspian, and adduced proofs of the greater extent of the latter sea at no distant era in the earth's history. His memoir on the fossil bones of Siberia attracted attention to some of the most remarkable phenomena in geology. He stated that he had found a rhinoceros entire in the frozen soil, with its skin and flesh: an elephant, found afterwards in a mass of ice on the shore of the North Sea, removed all doubt as to the credibility of so wonderful a discovery.*

The subjects relating to natural history which engaged the attention of Pallas, were too multifarious to admit of his devoting a large share of his labours exclusively to geology. Saussure, on the other hand, employed the chief portion of his time in studying the structure of the Alps and Jura, and he provided valuable data for those who followed him. He did not pretend to deduce any general system from his numerous observations; and the few theoretical opinions which escaped from him, seem, like those of Pallas, to have been chiefly derived from the cosmological speculations of preceding writers.

* Nov. comm. Pétr. XVII. Cuvier, Éloge de Pallas.

CHAPTER IV.

HISTORY OF THE PROGRESS OF GEOLOGY—*continued.*

WERNER'S APPLICATION OF GEOLOGY TO THE ART OF MINING—EXCURSIVE CHARACTER OF HIS LECTURES—ENTHUSIASM OF HIS PUPILS—HIS AUTHORITY—HIS THEORETICAL ERRORS—DESMAREST'S MAP AND DESCRIPTION OF AUVERGNE—CONTROVERSY BETWEEN THE VULCANISTS AND NEPTUNISTS—INTEMPERANCE OF THE RIVAL SECTS—HUTTON'S THEORY OF THE EARTH—HIS DISCOVERY OF GRANITE VEINS—ORIGINALITY OF HIS VIEWS—WHY OPPOSED—PLAYFAIR'S ILLUSTRATIONS—INFLUENCE OF VOLTAIRE'S WRITINGS ON GEOLOGY—IMPUTATIONS CAST ON THE HUTTONIANS BY WILLIAMS, KIRWAN, AND DE LUC—SMITH'S MAP OF ENGLAND—GEOLOGICAL SOCIETY OF LONDON—PROGRESS OF THE SCIENCES IN FRANCE—GROWING IMPORTANCE OF THE STUDY OF ORGANIC REMAINS.

WERNER.—The art of mining had long been taught in France, Germany, and Hungary, in scientific institutions established for that purpose, where mineralogy has always been a principal branch of instruction.

Werner was named, in 1775, professor of that science in the 'School of Mines,' at Freyberg, in Saxony. He directed his attention not merely to the composition and external characters of minerals, but also to what he termed 'geognosy,' or the natural position of minerals in particular rocks, together with the grouping of those rocks, their geographical distribution, and various relations. The phenomena observed in the structure of the globe had hitherto served for little else than to furnish interesting topics for philosophical discussion: but when Werner pointed out their application to the practical purposes of mining, they were instantly regarded by a large class of men as an essential part of their professional education, and from that time the science was cultivated in Europe more ardently and systematically. Werner's mind was at once imaginative and richly stored with miscellaneous knowledge. He associated every thing

with his favourite science, and in his excursive lectures, he pointed out all the economical uses of minerals, and their application to medicine: the influence of the mineral composition of rocks upon the soil, and of the soil upon the resources, wealth, and civilisation of man. The vast sandy plains of Tartary and Africa, he would say, retained their inhabitants in the shape of wandering shepherds; the granitic mountains and the low calcareous and alluvial plains gave rise to different manners, degrees of wealth, and intelligence. The history even of languages, and the migrations of tribes, had been determined by the direction of particular strata. The qualities of certain stones used in building would lead him to descant on the architecture of different ages and nations; and the physical geography of a country frequently invited him to treat of military tactics. The charm of his manners and his eloquence kindled enthusiasm in the minds of his pupils; and many, who had intended at first only to acquire a slight knowledge of mineralogy, when they had once heard him, devoted themselves to it as the business of their lives. In a few years, a small school of mines, before unheard of in Europe, was raised to the rank of a great university; and men already distinguished in science studied the German language, and came from the most distant countries to hear the great oracle of geology.*

Werner had a great antipathy to the mechanical labour of writing, and, with the exception of a valuable treatise on metalliferous veins, he could never be persuaded to pen more than a few brief memoirs, and those containing no development of his general views. Although the natural modesty of his disposition was excessive, approaching even to timidity, he indulged in the most bold and sweeping generalisations, and he inspired all his scholars with a most implicit faith in his doctrines. Their admiration of his genius, and the feelings of gratitude and friendship which they all felt for him, were not undeserved; but the supreme authority usurped by him over the opinions of his contemporaries, was eventually prejudicial to the progress of the science; so much so, as

* Cuvier, Éloge de Werner.

greatly to counterbalance the advantages which it derived from his exertions. If it be true that delivery be the first, second, and third requisite in a popular orator, it is no less certain, that to travel is of first, second, and third importance to those who desire to originate just and comprehensive views concerning the structure of our globe. Now Werner had not travelled to distant countries; he had merely explored a small portion of Germany, and conceived and persuaded others to believe that the whole surface of our planet, and all the mountain-chains in the world, were made after the model of his own province. It became a ruling object of ambition in the minds of his pupils to confirm the generalisations of their great master, and to discover in the most distant parts of the globe his 'universal formations,' which he supposed had been each in succession simultaneously precipitated over the whole earth from a common menstruum, or 'chaotic fluid.' It now appears that the Saxon professor had misinterpreted many of the most important appearances even in the immediate neighbourhood of Freyberg. Thus, for example, within a day's journey of his school, the porphyry, called by him primitive, has been found not only to send forth veins or dikes through strata of the coal formation, but to overlie them in mass. The granite of the Hartz mountains, on the other hand, which he supposed to be the nucleus of the chain, is now well known to traverse the other beds, as near Goslar; and still nearer Freyberg, in the Erzgebirge, the mica slate does not mantle round the granite as was supposed, but abuts abruptly against it. Fragments, also, of the greywacke slate, containing organic remains, were found entangled in the granite of the Hartz, by M. de Seckendorf.*

The principal merit of Werner's system of instruction consisted in steadily directing the attention of his scholars to the constant relations of superposition of certain mineral groups; but he had been anticipated, as has been shown in the last chapter, in the discovery of this general law, by

* I am indebted for this information partly to Messrs. Sedgwick and Murchison, who have investigated the country, and partly to Dr. Charles Hartmann, the translator of this work into German.

several geologists in Italy and elsewhere; and his leading divisions of the secondary strata were at the same time, and independently, made the basis of an arrangement of the British strata by our countryman, William Smith, to whose work I shall refer in the sequel.

Controversy between the Vulcanists and Neptunists.—In regard to basalt and other igneous rocks, Werner's theory was original, but it was also extremely erroneous. The basalts of Saxony and Hesse, to which his observations were chiefly confined, consisted of tabular masses capping the hills, and not connected with the levels of existing valleys, like many in Auvergne and the Vivarais. These basalts, and all other rocks of the same family in other countries, were, according to him, chemical precipitates from water. He denied that they were the products of submarine volcanos; and even taught that, in the primeval ages of the world, there were no volcanos. His theory was opposed, in a twofold sense, to the doctrine of the permanent agency of the same causes in nature; for not only did he introduce, without scruple, many imaginary causes supposed to have once effected great revolutions in the earth, and then to have become extinct, but new ones also were feigned to have come into play in modern times; and, above all, that most violent instrument of change, the agency of subterranean heat.

So early as 1768, before Werner had commenced his mineralogical studies, Raspe had truly characterised the basalts of Hesse as of igneous origin. Arduino, we have seen, had pointed out numerous varieties of trap-rock in the Vicentin as analogous to volcanic products, and as distinctly referable to ancient submarine eruptions. Desmarest, as before stated (p. 61), had, in company with Fortis, examined the Vicentin in 1766, and confirmed Arduino's views. In 1772, Banks, Solander, and Troil compared the columnar basalt of Hecla with that of the Hebrides. Collini, in 1774, recognised the true nature of the igneous rocks on the Rhine, between Andernach and Bonn. In 1775, Guettard visited the Vivarais, and established the relation of basaltic currents to lavas. Lastly, in 1779, Faujas published his

description of the volcanos of the Vivarais and Velay, and showed how the streams of basalt had poured out from craters which still remain in a perfect state.*

Desmarest.—When sound opinions had thus for twenty years prevailed in Europe concerning the true nature of the ancient trap-rocks, Werner by his simple dictum caused a retrograde movement, and not only overturned the true theory, but substituted for it one of the most unphilosophical that can well be imagined. The continual ascendency of his dogmas on this subject was the more astonishing, because a variety of new and striking facts were daily accumulated in favour of the correct opinions previously entertained. Desmarest, after a careful examination of Auvergne, pointed out, first, the most recent volcanos which had their craters still entire, and their streams of lava conforming to the level of the present river-courses. He then showed that there were others of an intermediate epoch, whose craters were nearly effaced, and whose lavas were less intimately connected with the present valleys; and, lastly, that there were volcanic rocks, still more ancient, without any discernible craters or scoriæ, and bearing the closest analogy to rocks in other parts of Europe, the igneous origin of which was denied by the school of Freyberg.†

Desmarest's map of Auvergne was a work of uncommon merit. He first made a trigonometrical survey of the district, and delineated its physical geography with minute accuracy and admirable graphic power. He contrived, at the same time, to express without the aid of colours, many geological details, including the different ages, and sometimes even the structure, of the volcanic rocks, and distinguishing them from the fresh-water and the granitic. They alone who have carefully studied Auvergne, and traced the different lava streams from their craters to their termination,—the various isolated basaltic cappings,—the relation of some lavas to the present valleys,—the absence of such relations in others,—can appreciate the extraordinary fidelity of this elaborate work. No other district of equal dimensions in Europe exhibits, perhaps,

* Cuvier, Éloge de Desmarest.

† Journ. de Phys. vol. xiii. p. 115; and Mém. de l'Inst., Sciences mathémat. et phys. vol. vi. p. 219.

so beautiful and varied a series of phenomena; and, fortunately, Desmarest possessed at once the mathematical knowledge required for the construction of a map, skill in mineralogy, and a power of original generalisation.

Dolomieu—Montlosier, 1784–1788.—Dolomieu, another of Werner's contemporaries, had found prismatic basalt among the ancient lavas of Etna; and, in 1784, had observed the alternations of submarine lavas and calcareous strata in the Val di Noto, in Sicily.* In 1790, also, he described similar phenomena in the Vicentin and in the Tyrol.† Montlosier published, in 1788, an essay on the theory of the volcanos of Auvergne, combining accurate local observations with comprehensive views. Notwithstanding this mass of evidence, the scholars of Werner were prepared to support his opinions to their utmost extent; maintaining, in the fulness of their faith, that even obsidian was an aqueous precipitate. As they were blinded by their veneration for the great teacher, they were impatient of opposition, and soon imbibed the spirit of a faction; and their opponents, the Vulcanists, were not long in becoming contaminated with the same intemperate zeal. Ridicule and irony were weapons more frequently employed than arguments by the rival sects, till at last the controversy was carried on with a degree of bitterness almost unprecedented in questions of physical science. Desmarest alone, who had long before provided ample materials for refuting such a theory, kept aloof from the strife; and whenever a zealous Neptunist wished to draw the old man into an argument, he was satisfied with replying, 'Go and see.'‡

Hutton, 1788.—It would be contrary to all analogy, in matters of graver import, that a war should rage with such fury on the Continent, and that the inhabitants of our island should not mingle in the affray. Although in England the personal influence of Werner was wanting to stimulate men to the defence of the weaker side of the question, they contrived to find good reason for espousing the Wernerian errors with great enthusiasm. In order to explain the peculiar

* Journ. de Phys. xxv. p. 191.

† Ibid. tom. xxxvii. part ii. p. 200.

‡ Cuvier, Éloge de Desmarest.

motives which led many to enter, even with party feeling, into this contest, it will be necessary to present the reader with a sketch of the views unfolded by Hutton, a contemporary of the Saxon geologist. Hutton had been educated as a physician, but declining the practice of medicine, he resolved, when young, to remain content with the small independence inherited from his father, and thenceforth to give his undivided attention to scientific pursuits. He resided at Edinburgh, where he enjoyed the society of many men of high atainments, who loved him for the simplicity of his manners and the sincerity of his character. His application was unwearied; and he made frequent tours through different parts of England and Scotland, acquiring considerable skill as a mineralogist, and constantly arriving at grand and comprehensive views in geology. He communicated the results of his observations unreservedly and with the fearless spirit of one who was conscious that love of truth was the sole stimulus of his exertions. When at length he had matured his views, he published, in 1788, his 'Theory of the Earth,'* and the same, afterwards more fully developed in a separate work, in 1795. This treatise was the first in which geology was declared to be in no way concerned about 'questions as to the origin of things;' the first in which an attempt was made to dispense entirely with all hypothetical causes, and to explain the former changes of the earth's crust by reference exclusively to natural agents. Hutton laboured to give fixed principles to geology, as Newton had succeeded in doing to astronomy; but, in the former science, too little progress had been made towards furnishing the necessary data, to enable any philosopher, however great his genius, to realise so noble a project.

Huttonian theory.—'The ruins of an older world,' said Hutton, 'are visible in the present structure of our planet; and the strata which now compose our continents have been once beneath the sea, and were formed out of the waste of pre-existing continents. The same forces are still destroying, by chemical decomposition or mechanical violence, even the hardest rocks, and transporting the materials to the sea,

* Ed. Phil. Trans. 1788.

where they are spread out, and form strata analogous to those of more ancient date. Although loosely deposited along the bottom of the ocean, they become afterwards altered and consolidated by volcanic heat, and then heaved up, fractured, and contorted.'

Although Hutton had never explored any region of active volcanos, he had convinced himself that basalt and many other trap-rocks were of igneous origin, and that some of them had been injected in a melted state through fissures in the older strata. The compactness of these rocks, and their different aspect from that of ordinary lava, he attributed to their having cooled down under the pressure of the sea; and in order to remove the objections started against this theory, his friend, Sir James Hall, instituted a most curious and instructive series of chemical experiments, illustrating the crystalline arrangement and texture assumed by melted matter cooled under high pressure.

The absence of stratification in granite, and its analogy, in mineral character, to rocks which he deemed of igneous origin, led Hutton to conclude that granite also must have been formed from matter in fusion; and this inference he felt could not be fully confirmed, unless he discovered at the contact of granite and other strata a repetition of the phenomena exhibited so constantly by the trap-rocks. Resolved to try his theory by this test, he went to the Grampians, and surveyed the line of junction of the granite and superincumbent stratified masses, until he found in Glen Tilt, in 1785, the most clear and unequivocal proofs in support of his views. Veins of red granite are there seen branching out from the principal mass, and traversing the black micaceous schist and primary limestone. The intersected stratified rocks are so distinct in colour and appearance as to render the example in that locality most striking, and the alteration of the limestone in contact was very analogous to that produced by trap veins on calcareous strata. This verification of his system filled him with delight, and called forth such marks of joy and exultation, that the guides who accompanied him, says his biographer, were convinced that he must have discovered a vein of

silver or gold.* He was aware that the same theory would not explain the origin of the primary schists, but these he called primary, rejecting the term primitive, and was disposed to consider them as sedimentary rocks altered by heat, and that they originated in some other form from the waste of previously existing rocks.

By this important discovery of granite veins, to which he had been led by fair induction from an independent class of facts, Hutton prepared the way for the greatest innovation on the systems of his predecessors. Vallisneri had pointed out the general fact that there were certain fundamental rocks which contained no organic remains, and which he supposed to have been formed before the creation of living beings. Moro, Generelli, and other Italian writers, embraced the same doctrine; and Lehman regarded the mountains called by him primitive, as parts of the original nucleus of the globe. The same tenet was an article of faith in the school of Freyberg: and if anyone ventured to doubt the possibility of our being enabled to carry back our researches to the creation of the present order of things, the granitic rocks were triumphantly appealed to. On them seemed written, in legible characters, the memorable inscription—

> Dinanzi a me non fur cose create
> Se non eterne; †

and no small sensation was excited when Hutton seemed, with unhallowed hand, desirous to erase characters already regarded by many as sacred. 'In the economy of the world,' said the Scotch geologist, 'I can find no traces of a beginning, no prospect of an end;' a declaration the more startling when coupled with the doctrine, that all past changes on the globe had been brought about by the slow agency of existing causes. The imagination was first fatigued and overpowered by endeavouring to conceive the immensity of time required for the annihilation of whole

* Playfair's Works, vol. iv. p. 75.

† 'Before me things create were none, save things
Eternal.'

Dante's *Inferno*, canto iii., Cary's Translation.

continents by so insensible a process; and when the thoughts had wandered through these interminable periods, no resting-place was assigned in the remotest distance. The oldest rocks were represented to be of a derivative nature, the last of an antecedent series, and that, perhaps, one of many pre-existing worlds. Such views of the immensity of past time, like those unfolded by the Newtonian philosophy in regard to space, were too vast to awaken ideas of sublimity unmixed with a painful sense of our incapacity to conceive a plan of such infinite extent. Worlds are seen beyond worlds immeasurably distant from each other, and, beyond them all, innumerable other systems are faintly traced on the confines of the visible universe.

The characteristic feature of the Huttonian theory was, as before hinted, the exclusion of all causes not supposed to belong to the present order of nature. But Hutton had made no step beyond Hooke, Moro, and Raspe, in pointing out in what manner the laws now governing subterranean movements might bring about geological changes, if sufficient time be allowed. On the contrary, he seems to have fallen far short of some of their views, especially when he refused to attribute any part of the external configuration of the earth's crust to subsidence. He imagined that the continents were first gradually destroyed by aqueous degradation; and when their ruins had furnished materials for new continents, they were upheaved by violent convulsions. He therefore required alternate periods of general disturbance, and repose: and such he believed had been, and would for ever be, the course of nature.

Generelli, in his exposition of Moro's system, had made a far nearer approximation towards reconciling geological appearances with the state of nature as known to us; for while he agreed with Hutton, that the decay and reproduction of rocks were always in progress, proceeding with the utmost uniformity, the learned Carmelite represented the repairs of mountains by elevation from below to be effected by an equally constant and synchronous operation. Neither of these theories, considered singly, satisfies all the conditions of the great problem, which a geologist, who rejects cosmo-

logical causes, is called upon to solve; but they probably contain together the germs of a perfect system. There can be no doubt, that periods of disturbance and repose have followed each other in succession in every region of the globe; but it may be equally true, that the energy of the subterranean movements has been always uniform as regards the *whole earth*. The force of earthquakes may for a cycle of years have been invariably confined, as it is now, to large but determinate spaces, and may then have gradually shifted its position, so that another region, which had for ages been at rest, became in its turn the grand theatre of action.

Playfair's illustrations of Hutton, 1797.—In the explanation proposed by Hutton, and by Playfair, the illustrator of his theory, respecting the origin of valleys, great stress was laid on the action of the rivers now flowing in them. They perhaps ascribed valleys in general too exclusively to this one cause. Yet Playfair, in speaking of the upper valley of the Rhone (see chap. xviii.), has shown that he did not wholly disregard the influence of subterranean movements, and of the waves of the sea, during the original emergence of the land.

Although Hutton's knowledge of mineralogy and chemistry was considerable, he possessed but little information concerning organic remains; they merely served him, as they did Werner, to characterise certain strata, and to prove their marine origin. The theory of former revolutions in organic life was not yet fully recognised; and without this class of proofs in support of the antiquity of the globe, the indefinite periods demanded by the Huttonian hypothesis appeared visionary to many; and some, who deemed the doctrine inconsistent with revealed truths, indulged very uncharitable suspicions of the motives of its author. They accused him of a deliberate design of reviving the heathen dogma of an 'eternal succession,' and of denying that this world ever had a beginning. Playfair, in the biography of his friend, has the following comment on this part of their theory: 'In the planetary motions, where geometry has carried the eye so far, both into the future and the past, we discover no mark either of the commencement or

termination of the present order. It is unreasonable, indeed, to suppose that such marks should anywhere exist. The Author of Nature has not given laws to the universe, which, like the institutions of men, carry in themselves the elements of their own destruction. He has not permitted in His works any symptom of infancy or of old age, or any sign by which we may estimate either their future or their past duration. *He may put an end, as He no doubt gave a beginning,* to the present system, at some determinate period of time; but we may rest assured that this great catastrophe will not be brought about by the laws now existing, and that it is not indicated by anything which we perceive.' *

The party feeling excited against the Huttonian doctrines, and the open disregard of candour and temper in the controversy, will hardly be credited by the reader, unless he recalls to his recollection that the mind of the English public was at that time in a state of feverish excitement. A class of writers in France had been labouring industriously for many years, to diminish the influence of the clergy, by sapping the foundations of the Christian faith; and their success, and the consequences of the Revolution, had alarmed the most resolute minds, while the imagination of the more timid was continually haunted by dread of innovation, as by the phantom of some fearful dream.

Voltaire, 1730–1760.—Although Voltaire was actively engaged throughout the greater part of his literary career in a successful war against religious intolerance, and in defence of those who were persecuted for opinions to which they had been led by freedom of enquiry, yet he contemplated with no friendly feelings the cultivators of geology in general. He found that the most popular systems of geology had been accommodated with much ingenuity to the account given in Genesis of the creation and deluge, and he regarded the science as one which had been successfully enlisted by the theologians as an ally in their cause.

When ridiculing the theories of Burnet, Woodward, and other physico-theological writers, he declared that they were

* Playfair's Works, vol. iv. p. 55.

as fond of changes of scene on the face of the globe as were the populace at a play. 'Every one of them destroys and renovates the earth after his own fashion, as Descartes framed it: for philosophers put themselves without ceremony in the place of God, and think to create a universe with a word.'* In his anxiety to shake the popular belief in the universal deluge, he endeavoured to inculcate scepticism as to the real nature of fossil shells, and to recall from contempt the exploded dogma of the sixteenth century that they were sports of nature. Yet in his later writings, speaking of the fossil shells of Touraine, he admits their organic origin, and in another of his works we find him implying the true nature of the shells collected in the Alps and other places, by ascribing them to Eastern species which had fallen from the hats of pilgrims coming from Syria.

Cowper—Williams, 1785–1789.—Some faint idea may be formed of the obloquy to which geologists exposed themselves by announcing the most obvious results of their investigations, if we observe the manner in which they were mentioned even by the amiable poet Cowper. In his poem of 'The Task' he says:

> Some drill and bore
> The solid earth, and from the strata there
> Extract a register, by which we learn
> That He who made it, and revealed its date
> To Moses, was mistaken in its age.†

The date here alluded to for the creation of this planet, or rather of the universe, was 4004 years before the birth of Christ; a date which for more than eighty years before Cowper published 'The Task' had been printed in the authorised versions of the Bible in the margin of the first chapter of Genesis, and was regarded by millions with the same reverence as the text of the Bible itself. Cowper was probably as little aware as are the majority of the present readers of this version that this chronology was derived from the speculations of Usher, Archbishop of Armagh, and is

* Dissertation envoyée à l'Académie de Boulogne, sur les Changemens arrivés dans notre Globe.

† The Task, book iii., 'The Garden.'

nowhere to be found in the narrative of the unknown author or authors of the Hebrew cosmogony.*

To pass over the works of many divines, it may be mentioned that among the foremost ranks of the intolerant at this period are found several laymen who had considerable claims to scientific reputation. Among these appears Williams, a mineral surveyor of Edinburgh, who published a 'Natural History of the Mineral Kingdom,' in 1789; a work of great merit for that day, and of practical utility, as containing the best account of the coal strata. In his preface he charges Hutton with 'warping everything to support the eternity of the world.'† He descants on the pernicious influence of such sceptical notions, as leading to downright infidelity and atheism, 'and as being nothing less than to depose the Almighty Creator of the universe from His office.'‡

De Luc—Kirwan, 1798.—De Luc, in the preliminary discourse to his Treatise on Geology§ says, 'the weapons have been changed by which revealed religion is attacked; it is now assailed by geology, and the knowledge of this science has become essential to theologians.' He imputes the failure of former geological systems to their having been anti-Mosaical. It might be supposed from these and other similar charges that the geologists of that age were animated by a polemical and aggressive spirit, but, on the contrary, those writers who were fortunate enough 'to discover the true causes of things,' rarely deserved another part of the poet's panegyric, '*Atque metus omnes subjecit pedibus.*' The caution, and even timid reserve, of many eminent authors in Italy and elsewhere from the early period to that at which we have now arrived is very apparent; and there can hardly be a doubt, that they subscribed to certain dogmas, and particularly to the first diluvian theory, out of deference to

* The date of 4004 years B.C. for the creation was published (see Horner, Presidential Address, Quart. Geol. Journ. 1861, p. lxix) in 1701 in an edition of the Bible now to be seen in the British Museum, and is continued up to the present time (1871) in the large annual reprints given out from the Clarendon Press at Oxford.

† P. 577.

‡ P. 59.

§ London, 1809.

popular prejudices, rather than from conviction. If they were guilty of dissimulation, we may feel regret, but must not blame their want of moral courage, reserving rather our condemnation for the persecuting spirit of the times, which forced Galileo to abjure, and the two Jesuits to disclaim the theory of Newton.

According to De Luc, the first essential distinction to be made between the various phenomena exhibited on the surface of the earth was, to determine which were the results of causes still in action, and which had been produced by causes that had ceased to act. The form and composition of the mass of our continents, he said, and their existence above the level of the sea, must be ascribed to causes no longer in action. These continents emerged, at no very remote period, on the sudden retreat of the ocean, the waters of which made their way into subterranean caverns. The formation of the rocks which enter into the crust of the earth began with the precipitation of granite from a primordial liquid, after which other strata containing the remains of organised bodies were deposited, till at last the present sea remained as the residuum of the primordial liquid, and no longer continued to produce mineral strata.*

Kirwan, president of the Royal Academy of Dublin, a chemist and mineralogist of some merit, but who possessed much greater authority in the scientific world than he was entitled by his talents to enjoy, said, in the introduction to his 'Geological Essays, 1799,' 'that *sound* geology *graduated* into religion, and was required to dispel certain systems of atheism or infidelity, of which they had had recent experience.'† He was an uncompromising defender of the aqueous theory of all rocks, and was scarcely surpassed by Burnet and Whiston, in his desire to adduce the Mosaic writings in confirmation of his opinions.

Hutton answered Kirwan's attacks with great warmth, and with the indignation justly excited by unmerited reproach. 'He had always displayed,' says Playfair, 'the utmost disposition to admire the beneficent design manifested in the

* Elementary Treatise on Geology. London, 1809. Translated by De la Fite.

† Introd. p. 2.

structure of the world; and he contemplated with delight those parts of his theory which made the greatest additions to our knowledge of final causes.' We may say with equal truth, that in no scientific works in our language can more eloquent passages be found, concerning the fitness, harmony, and grandeur of all parts of the creation, than in those of Playfair. They are evidently the unaffected expressions of a mind, which contemplated the study of nature, as best calculated to elevate our conceptions of the attributes of the First Cause. At any other time the force and elegance of Playfair's style must have insured popularity to the Huttonian doctrines; but by a singular coincidence, Neptunianism and orthodoxy were now associated in the same creed; and the tide of prejudice ran so strong, that the majority were carried far away into the chaotic fluid, and other cosmological inventions of Werner. These fictions the Saxon professor had borrowed with little modification, and without any improvement, from his predecessors. They had not the smallest foundation either in Scripture or in common sense, and were probably approved of by many as being so ideal and unsubstantial, that they could never come into violent collision with any preconceived opinions.

William Smith, 1790.—While the tenets of the rival schools of Freyberg and Edinburgh were warmly espoused by devoted partisans, the labours of an individual, unassisted by the advantages of wealth or station in society, were almost unheeded. Mr. William Smith, an English surveyor, published his 'Tabular View of the British Strata' in 1790, wherein he proposed a classification of the secondary formations in the West of England. Although he had not communicated with Werner, it appeared by this work that he had arrived at the same views respecting the laws of superposition of stratified rocks; that he was aware that the order of succession of different groups was never inverted; and that they might be identified at very distant points by their peculiar organised fossils.

From the time of the appearance of the 'Tabular View,' the author laboured to construct a geological map of the whole of England; and with the greatest disinterestedness of mind,

communicated the results of his investigations to all who desired information, giving such publicity to his original views, as to enable his contemporaries almost to compete with him in the race. The execution of his map was completed in 1815, and remains a lasting monument of original talent and extraordinary perseverance; for he had explored the whole country on foot without the guidance of previous observers, or the aid of fellow-labourers, and had succeeded in throwing into natural divisions the whole complicated series of British rocks. D'Aubuisson, a distinguished pupil of Werner, paid a just tribute of praise to this remarkable performance, observing, that 'what many celebrated mineralogists had only accomplished for a small part of Germany in the course of half a century, had been effected by a single individual for the whole of England.'*

Werner invented a new language to express his divisions of rocks, and some of his technical terms, such as greywacke, gneiss, and others, passed current in every country in Europe. Smith adopted for the most part English provincial terms, often of barbarous sound, such as gault, cornbrash, clunch clay; and affixed them to subdivisions of the British series. Many of these still retain their place in our scientific classifications and attest his priority of arrangement.

MODERN PROGRESS OF GEOLOGY.

The contention of the rival factions of the Vulcanists and Neptunists had been carried to such a height, that these names had become terms of reproach; and the two parties had been less occupied in searching for truth, than for such arguments as might strengthen their own cause or serve to annoy their antagonists. A new school at last arose, which professed the strictest neutrality, and the utmost indifference to the systems of Werner and Hutton, and which resolved diligently to devote its labours to observation. The reaction, provoked by the intemperance of the conflicting parties, now produced a tendency to extreme caution. Speculative views were discountenanced, and, through fear of exposing

* See Dr. Fitton's Memoir, before cited, p. 60.

themselves to the suspicion of a bias towards the dogmas of a party, some geologists became anxious to entertain no opinion whatever on the causes of phenomena, and were inclined to scepticism even where the conclusions deducible from observed facts scarcely admitted of reasonable doubt.

Geological Society of London, 1807.—But although the reluctance to theorise was carried somewhat to excess, no measure could be more salutary at such a moment than a suspension of all attempts to form what were termed 'theories of the earth.' A great body of new data was required; and the Geological Society of London, founded in 1807, conduced greatly to the attainment of this desirable end. To multiply and record observations, and patiently to await the result at some future period, was the object proposed by them; and it was their favourite maxim that the time was not yet come for a general system of geology, but that all must be content for many years to be exclusively engaged in furnishing materials for future generalisations. By acting up to these principles with consistency, they in a few years disarmed all prejudice, and rescued the science from the imputation of being a dangerous, or at best but a visionary pursuit.

A distinguished modern writer has with truth remarked, that the advancement of three of the main divisions of geological enquiry has, since the middle of the eighteenth century, been promoted successively by three different nations of Europe—the Germans, the English, and the French.* We have seen that the systematic study of what may be called mineralogical geology had its origin and chief point of activity in Germany, where Werner first described with precision the mineral characters of rocks. The classification of the secondary formations, each marked by their peculiar fossils, belongs, in a great measure, to England, where the labours before alluded to of Smith, and those of the most active members of the Geological Society of London, were steadily directed to these objects. The foundation of the third branch, that relating to the tertiary formations, was

* Whewell, British Critic, No. xvii. p. 187. 1831.

laid in France by the splendid work of Cuvier and Brongniart, published in 1808, 'On the Mineral Geography and Organic Remains of the Neighbourhood of Paris.'

We may still trace, in the language of the science and our present methods of arrangement, the various countries where the growth of these several departments of geology was at different times promoted. Many names of simple minerals and rocks remain to this day German; while the European divisions of the secondary strata are in great part English, and are, indeed, often founded too exclusively on English types. Lastly, the subdivisions first established in the Paris basin have served as normal groups to which other tertiary deposits throughout Europe have been compared, even in cases where this standard was wholly inapplicable.

No period could have been more fortunate for the discovery, in the immediate neighbourhood of Paris, of a rich store of well-preserved fossils, than the commencement of the present century; for at no former era had Natural History been cultivated with such enthusiasm in the French metropolis. The labours of Cuvier in comparative osteology, and of Lamarck in recent and fossil shells, had raised these departments of study to a rank of which they had never previously been deemed susceptible. Their investigations had eventually a powerful effect in dispelling the illusion which had long prevailed concerning the absence of analogy between the ancient and modern state of our planet. A close comparison of the recent and fossil species, and the inferences drawn in regard to their habits, accustomed the geologist to contemplate the earth as having been at successive periods the dwelling-place of animals and plants of different races, some terrestrial, and others aquatic—some fitted to live in seas, others in the waters of lakes and rivers. By the consideration of these topics, the mind was slowly and insensibly withdrawn from imaginary pictures of catastrophes and chaotic confusion, such as haunted the imagination of the early cosmogonists. Numerous proofs were discovered of the tranquil deposition of sedimentary matter, and the slow development of organic life. If many writers, and Cuvier himself in the number, still continued to maintain that 'the thread of

induction was broken,'* yet, in reasoning by the strict rules of induction from recent to fossil species, they in a great measure disclaimed the dogma which in theory they professed. The adoption of the same generic, and, in some cases, even of the same specific, names for the exuviæ of fossil animals and their living analogues, was an important step towards familiarising the mind with the idea of the identity and unity of the system in distant eras. It was an acknowledgment, as it were, that part at least of the ancient memorials of nature were written in a living language. The growing importance, then, of the natural history of organic remains may be pointed out as the characteristic feature of the progress of the science during the present century. This branch of knowledge has already become an instrument of great utility in geological classification, and is continuing daily to unfold new data for grand and enlarged views respecting the former changes of the earth.

When we compare the results of observations in this century with those of the three preceding centuries, we cannot but look forward with the most sanguine expectations to the degree of excellence to which geology may be carried, even by the labours of the present generation. Never, perhaps, did any science, with the exception of astronomy, unfold, in an equally brief period, so many novel and unexpected truths, and overturn so many preconceived opinions. The senses had for ages declared the earth to be at rest, until the astronomer taught that it was carried through space with inconceivable rapidity. In like manner was the surface of this planet regarded as having remained unaltered since its creation, until the geologist proved that it had been the theatre of reiterated change, and was still the subject of slow but never-ending fluctuations. The discovery of other systems in the boundless regions of space was the triumph of astronomy; to trace the same system through various transformations—to behold it at successive eras adorned with different hills and valleys, lakes and seas, and peopled with new inhabitants, was the delightful meed of geological research. By the geometer

* Discours sur les Révolutions de la Terre.

were measured the regions of space, and the relative distances of the heavenly bodies;—by the geologist myriads of ages were reckoned, not by arithmetical computation, but by a train of physical events—a succession of phenomena in the animate and inanimate worlds—signs which convey to our minds more definite ideas than figures can do of the immensity of time.

Whether our investigation of the earth's history and structure will eventually be productive of as great practical benefits to mankind as a knowledge of the distant heavens, must remain for the decision of posterity. It was not till astronomy had been enriched by the observations of many centuries, and had made its way against popular prejudices to the establishment of a sound theory, that its application to the useful arts was most conspicuous. The cultivation of geology began at a later period; and in every step which it has hitherto made towards sound theoretical principles, it has had to contend against more violent prepossessions. The practical advantages already derived from it have not been inconsiderable; but our generalisations are yet imperfect, and they who come after us may be expected to reap the most valuable fruits of our labour. Meanwhile the charm of first discovery is our own; and, as we explore this magnificent field of enquiry, the sentiment of a great historian of our times may continually be present to our minds, that 'he who calls what has vanished back again into being enjoys a bliss like that of creating.' *

* Niebuhr's Hist. of Rome, vol. i. p. 5. Hare and Thirlwall's translation.

CHAPTER V.

PREJUDICES WHICH HAVE RETARDED THE PROGRESS OF GEOLOGY.

PREPOSSESSIONS IN REGARD TO THE DURATION OF PAST TIME—PREJUDICES ARISING FROM OUR PECULIAR POSITION AS INHABITANTS OF THE LAND—OTHERS OCCASIONED BY OUR NOT SEEING SUBTERRANEAN CHANGES NOW IN PROGRESS—ALL THESE CAUSES COMBINE TO MAKE THE FORMER COURSE OF NATURE APPEAR DIFFERENT FROM THE PRESENT—OBJECTIONS TO THE DOCTRINE THAT CAUSES SIMILAR IN KIND AND ENERGY TO THOSE NOW ACTING, HAVE PRODUCED THE FORMER CHANGES OF THE EARTH'S SURFACE, CONSIDERED.

If we reflect on the history of the progress of geology, as explained in the preceding chapters, we perceive that there have been great fluctuations of opinion respecting the nature of the causes to which all former changes of the earth's surface are referable. The first observers conceived the monuments which the geologist endeavours to decipher to relate to an original state of the earth, or to a period when there where causes in activity, distinct, in kind and degree, from those now constituting the economy of nature. These views were gradually modified, and some of them entirely abandoned, in proportion as observations were multiplied, and the signs of former mutations were skilfully interpreted. Many appearances, which had for a long time been regarded as indicating mysterious and extraordinary agency, were finally recognised as the necessary result of the laws now governing the material world; and the discovery of this unlooked-for conformity has at length induced some philosophers to infer, that, during the ages contemplated in geology, there has never been any interruption to the agency of the same uniform laws of change. The same assemblage of general causes, they conceive, may have been sufficient to produce, by their various combinations, the

endless diversity of effects, of which the shell of the earth has preserved the memorials; and, consistently with these principles, the recurrence of analogous changes is expected by them in time to come.

Whether we coincide or not in this doctrine, we must admit that the gradual progress of opinion concerning the succession of phenomena in very remote eras, resembles, in a singular manner, that which has accompanied the growing intelligence of every people, in regard to the economy of nature in their own times. In an early state of advancement, when a greater number of natural appearances are unintelligible, an eclipse, an earthquake, a flood, or the approach of a comet, with many other occurrences afterwards found to belong to the regular course of events, are regarded as prodigies. The same delusion prevails as to moral phenomena, and many of these are ascribed to the intervention of demons, ghosts, witches, and other immaterial and supernatural agents. By degrees, many of the enigmas of the moral and physical world are explained, and, instead of being due to extrinsic and irregular causes, they are found to depend on fixed and invariable laws. The philosopher at last becomes convinced of the undeviating uniformity of secondary causes; and, guided by his faith in this principle, he determines the probability of accounts transmitted to him of former occurrences, and often rejects the fabulous tales of former times, on the ground of their being irreconcilable with the experience of more enlightened ages.

Prepossessions in regard to the duration of past time.—As a belief in the want of conformity in the causes by which the earth's crust has been modified in ancient and modern periods was, for a long time, universally prevalent, and that, too, amongst men who were convinced that the order of nature had been uniform for the last several thousand years, every circumstance which could have influenced their minds and given an undue bias to their opinions deserves particular attention. Now the reader may easily satisfy himself, that, however undeviating the course of nature may have been from the earliest epochs, it was impossible for the first cultivators of geology to come to such a conclusion, so long

as they were under a delusion as to the age of the world, and the date of the first creation of animate beings. However fantastical some theories of the sixteenth century may now appear to us,—however unworthy of men of great talent and sound judgment,—we may rest assured that, if the same misconception now prevailed in regard to the memorials of human transactions, it would give rise to a similar train of absurdities. Let us imagine, for example, that Champollion, and the French and Tuscan literati when engaged in exploring the antiquities of Egypt, had visited that country with a firm belief that the banks of the Nile were never peopled by the human race before the beginning of the nineteenth century, and that their faith in this dogma was as difficult to shake as the opinion of our ancestors, that the earth was never the abode of living beings until the creation of the present continents, and of the species now existing,—it is easy to perceive what extravagant systems they would frame, while under the influence of this delusion, to account for the monuments discovered in Egypt. The sight of the pyramids, obelisks, colossal statues, and ruined temples, would fill them with such astonishment, that for a time they would be as men spell-bound—wholly incapable of reasoning with sobriety. They might incline at first to refer the construction of such stupendous works to some superhuman powers of a primeval world. A system might be invented resembling that so gravely advanced by Manetho, who relates that a dynasty of gods originally ruled in Egypt, of whom Vulcan, the first monarch, reigned nine thousand years; after whom came Hercules and other demigods, who were at last succeeded by human kings.

When some fanciful speculations of this kind had amused their imaginations for a time, some vast repository of mummies would be discovered, and would immediately undeceive those antiquaries who enjoyed an opportunity of personally examining them; but the prejudices of others at a distance, who were not eye-witnesses of the whole phenomena, would not be so easily overcome. The concurrent report of many travellers would, indeed, render it necessary for them to accommodate ancient theories to some of the new facts, and

much wit and ingenuity would be required to modify and defend their old positions. Each new invention would violate a greater number of known analogies; for if a theory be required to embrace some false principle, it becomes more visionary in proportion as facts are multiplied, as would be the case if geometers were now required to form an astronomical system on the assumption of the immobility of the earth.

Amongst other fanciful conjectures concerning the history of Egypt, we may suppose some of the following to be started. 'As the banks of the Nile have been so recently colonised for the first time, the curious substances called mummies could never in reality have belonged to men. They may have been generated by some *plastic virtue* residing in the interior of the earth, or they may be abortions of Nature produced by her incipient efforts in the work of creation. For if deformed beings are sometimes born even now, when the scheme of the universe is fully developed, many more may have been "sent before their time, scarce half made up," when the planet itself was in the embryo state. But if these notions appear to derogate from the perfection of the Divine attributes, and if these mummies be in all their parts true representations of the human form, may we not refer them to the future rather than the past? May we not be looking into the womb of Nature, and not her grave? May not these images be like the shades of the unborn in Virgil's Elysium—the archetypes of men not yet called into existence?'

These speculations, if advocated by eloquent writers, would not fail to attract many zealous votaries, for they would relieve men from the painful necessity of renouncing preconceived opinions. Incredible as such scepticism may appear, it has been rivalled by many systems of the sixteenth and seventeenth centuries, and among others by that of the learned Falloppio, who, as we have seen (p. 33), regarded the tusks of fossil elephants as earthy concretions, and the pottery or fragments of vases in the Monte Testaceo, near Rome, as works of nature, and not of art. But when one generation had passed away, and another, not compromised to the

support of antiquated dogmas, had succeeded, they would review the evidence afforded by mummies more impartially, and would no longer controvert the preliminary question, that human beings had lived in Egypt before the nineteenth century: so that when a hundred years perhaps had been lost, the industry and talents of the philosopher would be at last directed to the elucidation of points of real historical importance.

But the above arguments are aimed against one only of many prejudices with which the earlier geologists had to contend. Even when they conceded that the earth had been peopled with animate beings at an earlier period than was at first supposed, they had no conception that the quantity of time bore so great a proportion to the historical era as is now generally conceded. How fatal every error as to the quantity of time must prove to the introduction of rational views concerning the state of things in former ages, may be conceived by supposing the annals of the civil and military transactions of a great nation to be perused under the impression that they occurred in a period of one hundred instead of two thousand years. Such a portion of history would immediately assume the air of a romance; the events would seem devoid of credibility, and inconsistent with the present course of human affairs. A crowd of incidents would follow each other in thick succession. Armies and fleets would appear to be assembled only to be destroyed, and cities built merely to fall in ruins. There would be the most violent transitions from foreign or intestine war to periods of profound peace, and the works effected during the years of disorder or tranquillity would appear alike superhuman in magnitude.

He who should study the monuments of the natural world under the influence of a similar infatuation, must draw a no less exaggerated picture of the energy and violence of causes, and must experience the same insurmountable difficulty in reconciling the former and present state of nature. If we could behold in one view all the volcanic cones thrown up in Iceland, Italy, Sicily, and other parts of Europe, during the last five thousand years, and could see the lavas

which have flowed during the same period; the dislocations, subsidences, and elevations caused during earthquakes; the lands added to various deltas, or devoured by the sea, together with the effects of devastation by floods, and imagine that all these events had happened in one year, we must form most exalted ideas of the activity of the agents, and the suddenness of the revolutions. If geologists, therefore, have misinterpreted the signs of a succession of events, so as to conclude that centuries were implied where the characters indicated thousands of years, and thousands of years where the language of Nature signified millions, they could not, if they reasoned logically from such false premises, come to any other conclusion than that the system of the natural world had undergone a complete revolution.

We should be warranted in ascribing the erection of the great pyramid to superhuman power, if we were convinced that it was raised in one day; and if we imagine, in the same manner, a continent or mountain-chain to have been elevated during an equally small fraction of the time which was really occupied in upheaving it, we might then be justified in inferring, that the subterranean movements were once far more energetic than in our own times. We know that during one earthquake the coast of Chili may be raised for a hundred miles to the average height of about three feet. A repetition of two thousand shocks, of equal violence, might produce a mountain-chain one hundred miles long, and six thousand feet high. Now, should one or two only of these convulsions happen in a century, it would be consistent with the order of events experienced by the Chilians from the earliest times: but if the whole of them were to occur in the next hundred years, the entire district must be depopulated, scarcely any animals or plants could survive, and the surface would be one confused heap of ruin and desolation.

One consequence of undervaluing greatly the quantity of past time, is the apparent coincidence which it occasions of events necessarily disconnected, or which are so unusual, that it would be inconsistent with all calculation of chances to suppose them to happen at one and the same time. When the unlooked-for association of such rare phenomena is

witnessed in the present course of nature, it scarcely ever fails to excite a suspicion of the preternatural in those minds which are not firmly convinced of the uniform agency of secondary causes;—as if the death of some individual in whose fate they are interested happens to be accompanied by the appearance of a luminous meteor, or a comet, or the shock of an earthquake. It would be only necessary to multiply such coincidences indefinitely, and the mind of every philosopher would be disturbed. Now it would be difficult to exaggerate the number of physical events, many of them most rare and unconnected in their nature, which were imagined by the Woodwardian hypothesis to have happened in the course of a few months: and numerous other examples might be found of popular geological theories, which require us to imagine that a long succession of events happened in a brief and almost momentary period.

Another liability to error, very nearly allied to the former, arises from the frequent contact of geological monuments referring to very distant periods of time. We often behold, at one glance, the effects of causes which have acted at times incalculably remote, and yet there may be no striking circumstances to mark the occurrence of a great chasm in the chronological series of Nature's archives. In the vast interval of time which may really have elapsed between the results of operations thus compared, the physical condition of the earth may, by slow and insensible modifications, have become entirely altered; one or more races of organic beings may have passed away, and yet have left behind, in the particular region under contemplation, no trace of their existence.

To a mind unconscious of these intermediate events, the passage from one state of things to another must appear so violent, that the idea of revolutions in the system inevitably suggests itself. The imagination is as much perplexed by the deception, as it might be if two distant points in space were suddenly brought into immediate proximity. Let us suppose, for a moment, that a philosopher should lie down to sleep in some arctic wilderness, and then be transferred by a power, such as we read of in tales of enchantment, to a valley in a tropical country, where, on awaking, he might

find himself surrounded by birds of brilliant plumage, and all the luxuriance of animal and vegetable forms of which Nature is so prodigal in those regions. The most reasonable supposition, perhaps, which he could make, if by the necromancer's art he were placed in such a situation, would be, that he was dreaming; and if a geologist form theories under a similar delusion, we cannot expect him to preserve more consistency in his speculations than in the train of ideas in an ordinary dream.

It may afford, perhaps, a more lively illustration of the principle here insisted upon, if I recall to the reader's recollection the legend of the Seven Sleepers. The scene of that popular fable was placed in the two centuries which elapsed between the reign of the emperor Decius and the death of Theodosius the younger. In that interval of time (between the years 249 and 450 of our era) the union of the Roman empire had been dissolved, and some of its fairest provinces overrun by the barbarians of the north. The seat of government had passed from Rome to Constantinople, and the throne from a pagan persecutor to a succession of Christian and orthodox princes. The genius of the empire had been humbled in the dust, and the altars of Diana and Hercules were on the point of being transferred to Catholic saints and martyrs. The legend relates, 'that when Decius was still persecuting the Christians, seven noble youths of Ephesus concealed themselves in a spacious cavern in the side of an adjacent mountain, where they were doomed to perish by the tyrant, who gave orders that the entrance should be firmly secured with a pile of huge stones. They immediately fell into a deep slumber, which was miraculously prolonged, without injuring the powers of life, during a period of 187 years. At the end of that time the slaves of Adolius, to whom the inheritance of the mountain had descended, removed the stones to supply materials for some rustic edifice: the light of the sun darted into the cavern, and the seven sleepers were permitted to awake. After a slumber, as they thought, of a few hours, they were pressed by the calls of hunger, and resolved that Jamblichus, one of their number, should secretly return to the city to purchase bread

for the use of his companions. The youth could no longer recognise the once familiar aspect of his native country, and his surprise was increased by the appearance of a large cross triumphantly erected over the principal gate of Ephesus. His singular dress and obsolete language confounded the baker, to whom he offered an ancient medal of Decius as the current coin of the empire; and Jamblichus, on the suspicion of a secret treasure, was dragged before the judge. Their mutual enquiries produced the amazing discovery, that two centuries were almost elapsed since Jamblichus and his friends had escaped from the rage of a pagan tyrant.'

This legend was received as authentic throughout the Christian world before the end of the sixth century, and was afterwards introduced by Mahomet as a divine revelation into the Koran, and from hence was adopted and adorned by all the nations from Bengal to Africa who professed the Mahometan faith. Some vestiges even of a similar tradition have been discovered in Scandinavia. 'This easy and universal belief,' observes the philosophical historian of the Decline and Fall, 'so expressive of the sense of mankind, may be ascribed to the genuine merit of the fable itself. We imperceptibly advance from youth to age, without observing the gradual, but incessant, change of human affairs; and even, in our larger experience of history, the imagination is accustomed, by a perpetual series of causes and effects, to unite the most distant revolutions. But if the interval between two memorable eras could be instantly annihilated; if it were possible, after a momentary slumber of two hundred years, to display the new world to the eyes of a spectator who still retained a lively and recent impression of the old, his surprise and his reflections would furnish the pleasing subject of a philosophical romance.'*

Prejudices arising from our peculiar position as inhabitants of the land.—The sources of prejudice hitherto considered may be deemed peculiar for the most part to the infancy of the science, but others are common to the first cultivators of

* Gibbon, Decline and Fall, chap. xxxiii.

geology and to ourselves, and are all singularly calculated to produce the same deception, and to strengthen our belief that the course of nature in the earlier ages differed widely from that now established. Although these circumstances cannot be fully explained without assuming some things as proved, which it has been my object elsewhere to demonstrate,* it may be well to allude to them briefly in this place.

The first and greatest difficulty, then, consists in an habitual unconsciousness that our position as observers is essentially unfavourable, when we endeavour to estimate the nature and magnitude of the changes now in progress. In consequence of our inattention to this subject, we are liable to serious mistakes in contrasting the present with former states of the globe. As dwellers on the land, we inhabit about a fourth part of the surface; and that portion is almost exclusively a theatre of decay, and not of reproduction. We know, indeed, that new deposits are annually formed in seas and lakes, and that every year some new igneous rocks are produced in the bowels of the earth, but we cannot watch the progress of their formation; and as they are only present to our minds by the aid of reflection, it requires an effort both of the reason and the imagination to appreciate duly their importance. It is, therefore, not surprising that we estimate very imperfectly the result of operations thus unseen by us; and that, when analogous results of former epochs are presented to our inspection, we cannot immediately recognise the analogy. He who has observed the quarrying of stone from a rock, and has seen it shipped for some distant port, and then endeavours to conceive what kind of edifice will be raised by the materials, is in the same predicament as a geologist, who, while he is confined to the land, sees the decomposition of rocks, and the transportation of matter by rivers to the sea, and then endeavours to picture to himself the new strata which Nature is building beneath the waters.

Prejudices arising from our not seeing subterranean changes.—Nor is his position less unfavourable when, beholding a volcanic eruption, he tries to conceive what changes the

* Elements of Geology, 6th edit., 1865; and Student's Elements, 1871.

column of lava has produced, in its passage upwards, on the intersected strata; or what form the melted matter may assume at great depths on cooling; or what may be the extent of the subterranean rivers and reservoirs of liquid matter far beneath the surface. It should, therefore, be remembered, that the task imposed on those who study the earth's history requires no ordinary share of discretion; for we are precluded from collating the corresponding parts of the system of things as it exists now, and as it existed at former periods. If we were inhabitants of another element—if the great ocean were our domain, instead of the narrow limits of the land, our difficulties would be considerably lessened; while, on the other hand, there can be little doubt, although the reader may, perhaps, smile at the bare suggestion of such an idea, that an amphibious being, who should possess our faculties, would still more easily arrive at sound theoretical opinions in geology, since he might behold, on the one hand, the decomposition of rocks in the atmosphere, or the transportation of matter by running water; and, on the other, examine the deposition of sediment in the sea, and the imbedding of animal and vegetable remains in new strata. He might ascertain, by direct observation, the action of a mountain torrent, as well as of a marine current; might compare the products of volcanos poured out upon the land with those ejected beneath the waters; and might mark, on the one hand, the growth of the forest, and, on the other, that of the coral reef. Yet, even with these advantages, he would be liable to fall into the greatest errors, when endeavouring to reason on rocks of subterranean origin. He would seek in vain, within the sphere of his observation, for any direct analogy to the process of their formation, and would therefore be in danger of attributing them, wherever they are upraised to view, to some 'primeval state of nature.'

But if we may be allowed so far to indulge the imagination, as to suppose a being entirely confined to the nether world—some 'dusky melancholy sprite,' like Umbriel, who could 'flit on sooty pinions to the central earth,' but who was never permitted to 'sully the fair face of light,' and emerge into the regions of water and of air; and if this

being should busy himself in investigating the structure of the globe, he might frame theories the exact converse of those usually adopted by human philosophers. He might infer that the stratified rocks, containing shells and other organic remains, were the oldest of created things, belonging to some original and nascent state of the planet. 'Of these masses,' he might say, 'whether they consist of loose incoherent sand, soft clay, or solid stone, none have been formed in modern times. Every year some of them are broken and shattered by earthquakes, or melted by volcanic fire; and when they cool down slowly from a state of fusion, they assume a new and more crystalline form, no longer exhibiting that stratified disposition and those curious impressions and fantastic markings, by which they were previously characterised. This process cannot have been carried on for an indefinite time, for in that case all the stratified rocks would long ere this have been fused and crystallised. It is therefore probable that the whole planet once consisted of these mysterious and curiously bedded formations at a time when the volcanic fire had not yet been brought into activity. Since that period there seems to have been a gradual development of heat; and this augmentation we may expect to continue till the whole globe shall be in a state of fluidity, or shall consist, in those parts which are not melted, of volcanic and crystalline rocks.'

Such might be the system of the Gnome at the very time that the followers of Leibnitz, reasoning on what they saw on the outer surface, might be teaching the opposite doctrine of gradual refrigeration, and averring that the earth had begun its career as a fiery comet, and might be destined hereafter to become a frozen mass. The tenets of the schools of the nether and of the upper world would be directly opposed to each other, for both would partake of the prejudices inevitably resulting from the continual contemplation of one class of phenomena to the exclusion of another. Man observes the annual decomposition of crystalline and igneous rocks, and may sometimes see their conversion into stratified deposits; but he cannot witness the reconversion of the

sedimentary into the crystalline by subterranean heat. He is in the habit of regarding all the sedimentary rocks as more recent than the unstratified, for the same reason that we may suppose him to fall into the opposite error if he saw the origin of the igneous class only.

For more than two centuries the shelly strata of the Subapennine hills afforded matter of speculation to the early geologists of Italy, and few of them had any suspicion that similar deposits were then forming in the neighbouring sea. Some imagined that the strata, so rich in organic remains, instead of being due to secondary agents, had been so created in the beginning of things by the fiat of the Almighty. Others, as we have seen, ascribed the imbedded fossil bodies to some plastic power which resided in the earth in the early ages of the world. In what manner were these dogmas at length exploded? The fossil relics were carefully compared with their living analogues, and all doubts as to their organic origin were eventually dispelled. So, also, in regard to the nature of the containing beds of mud, sand, and limestone: those parts of the bottom of the sea were examined where shells are now becoming annually entombed in new deposits. Donati explored the bed of the Adriatic, and found the closest resemblance between the strata there forming, and those which constituted hills above a thousand feet high in various parts of the Italian peninsula. He ascertained by dredging that living testacea were there grouped together in precisely the same manner as were their fossil analogues in the inland strata; and while some of the recent shells of the Adriatic were becoming incrusted with calcareous rock, he observed that others had been newly buried in sand and clay, precisely as fossil shells occur in the Subapennine hills.

In like manner, the volcanic rocks of the Vicentin had been studied in the beginning of the last century; but no geologist suspected, before the time of Arduino, that these were composed of ancient submarine lavas. During many years of controversy, the popular opinion inclined to a belief that basalt and rocks of the same class had been precipitated from a chaotic fluid, or an ocean which rose at succes-

sive periods over the continents, charged with the component elements of the rocks in question. Few will now dispute that it would have been difficult to invent a theory more distant from the truth; yet we must cease to wonder that it gained so many proselytes, when we remember that its claims to probability arose partly from the very circumstance of its confirming the assumed want of analogy between geological causes and those now in action. By what train of investigations were geologists induced at length to reject these views, and to assent to the igneous origin of the trappean formations? By an examination of volcanos now active, and by comparing their structure and the composition of their lavas with the ancient trap rocks.

The establishment, from time to time, of numerous points of identification, drew at length from geologists a reluctant admission, that there was more correspondence between the condition of the globe at remote eras and now, and more uniformity in the laws which have regulated the changes of its surface, than they at first imagined. If, in this state of the science, they still despaired of reconciling every class of geological phenomena to the operations of ordinary causes, even by straining analogy to the utmost limits of credibility, we might have expected, at least, that the balance of probability would now have been presumed to incline towards the close analogy of the ancient and modern causes. But, after repeated experience of the failure of attempts to speculate on geological monuments, as belonging to a distinct order of things, new sects continued to persevere in the principles adopted by their predecessors. They still began, as each new problem presented itself, whether relating to the animate or inanimate world, to assume an original and dissimilar order of nature; and when at length they approximated, or entirely came round to an opposite opinion, it was always with the feeling, that they were conceding what they had been justified *à priori* in deeming improbable. In a word, the same men who, as natural philosophers, would have been most incredulous respecting any extraordinary deviations from the known course of nature, if reported to have happened *in their own time*, were equally disposed, as geologists,

to expect the proofs of such deviations at every period of the past.

I shall proceed in the following chapters to enumerate some of the principal difficulties still opposed to the theory of the uniform nature and energy of the causes which have worked successive changes in the crust of the earth, and in the condition of its living inhabitants. The discussion of so important a question on the present occasion may appear premature, but it is one which naturally arises out of a review of the former history of the science. It is, of course, impossible to enter into such speculative topics, without occasionally carrying the novice beyond his depth, and appealing to facts and conclusions with which he will be unacquainted, until he has studied some elementary work on geology, but it may be useful to excite his curiosity, and lead him to study such works by calling his attention at once to some of the principal points of controversy.*

* In the earlier editions of this work, a fourth book was added on Geology Proper, or Systematic Geology, containing an account of the former changes of the animate and inanimate creation, brought to light by an examination of the crust of the earth. This I afterwards (in 1838) expanded into a separate publication called the Elements or Manual of Geology, of which a sixth edition appeared, January 1865, and the greater part of which is embodied in the Student's Elements published in 1871.

CHAPTER VI.

SUPPOSED INTENSITY OF AQUEOUS FORCES AT REMOTE PERIODS.

INTENSITY OF AQUEOUS CAUSES—SLOW ACCUMULATION OF STRATA PROVED BY FOSSILS—RATE OF DENUDATION CAN ONLY KEEP PACE WITH DEPOSITION—ERRATICS, AND ACTION OF ICE—DELUGES, AND THE CAUSES TO WHICH THEY ARE REFERRED—SUPPOSED UNIVERSALITY OF ANCIENT DEPOSITS.

INTENSITY OF AQUEOUS CAUSES.—The great problem alluded to at the close of the last chapter may thus be stated, whether the former changes of the earth made known to us by geology resemble in kind and degree those now in daily progress. This question may be contemplated from several points of view, and it embraces among other subjects the enquiry, whether there are any grounds for the belief entertained by many, that the intensity both of aqueous and of igneous forces, in remote ages, far exceeded that which we witness in our own times.

First, then, as to aqueous causes: it has been shown in our history of the science, that Woodward did not hesitate, in 1695, to teach that the entire mass of fossiliferous strata contained in the earth's crust had been deposited in a few months; and, consequently, as their mechanical and derivative origin was already admitted, the reduction of rocky masses into mud, sand, and pebbles, the transportation of the same to a distance, and their accumulation elsewhere in regular strata, were all assumed to have taken place with a rapidity unparalleled in modern times. This doctrine was modified by degrees, in proportion as different classes of organic remains, such as shells, corals, and fossil plants, had been studied with attention. Analogy led every naturalist to assume, that each full-grown individual of the animal or vegetable kingdom, had required a certain number of days,

months, or years for the attainment of maturity, and the perpetuation of its species by generation; and thus the first approach was made to the conception of a common standard of time, without which there are no means whatever of measuring the comparative rate at which any succession of events has taken place at two distinct periods. This standard consisted of the average duration of the lives of individuals of the same genera or families in the animal and vegetable kingdoms; and the multitude of fossils dispersed through successive strata implied the continuance of the same species for many generations. At length the idea that species themselves had had a limited duration, arose out of the observed fact that sets of strata of different ages contained fossils of distinct species. Finally, the opinion became general, that in the course of ages, one assemblage of animals and plants had disappeared after another again and again, and new tribes had started into life to replace them.

Denudation.—In addition to the proofs derived from organic remains, the forms of stratification led also, on a fuller investigation, to the belief that sedimentary rocks had been slowly deposited; but it was still supposed that *denudation*, or the power of running water, and the waves and currents of the ocean, to strip off superior strata, and lay bare the rocks below, had formerly operated with an energy wholly unequalled in our times. These opinions were both illogical and inconsistent, because deposition and denudation are processes inseparably connected, and what is true of the rate of one of them must be true of the rate of the other within very narrow limits, and the conveyance of solid matter to a particular region can only keep pace with its removal from another, so that the aggregate of sedimentary strata in the earth's crust can never exceed in volume the amount of solid matter which has been ground down and washed away by rivers, waves, and currents. How vast then must be the spaces which this abstraction of matter has left vacant! how far exceeding in dimensions all the valleys, however numerous, and the hollows, however vast, which we can prove to have been cleared out by aqueous erosion! The evidence of the work of denudation is defective, because it is the tendency of every destroying cause to obliterate, in great part, the

signs of its own agency. The amount of reproduction in the form of sedimentary strata will only afford a measure of the minimum of denudation which the earth's surface has undergone, because the same materials in a multitude of cases have been broken up again and again and re-stratified, so that the last alone of many forms through which they have past is now presented to our view.

Erratics and ice-action.—Another phenomenon to which the advocates of the excessive power of running water in times past have appealed, is the enormous size of the blocks called *erratic*, which lie scattered over the northern parts of Europe and North America. Unquestionably a large proportion of these blocks have been transported far from their original position, for between them and the parent rocks we now find, not unfrequently, deep seas and valleys intervening, or hills more than a thousand feet high. To explain the present situation of such travelled fragments, a deluge of mud was imagined by some to have come from the north, bearing along with it sand, gravel, and stony fragments, some of them hundreds of tons in weight. This flood, in its transient passage over the continents, dispersed the boulders irregularly over hill, valley, and plain; or forced them along over a surface of hard rock, so as to polish it and leave it indented with parallel scratches and grooves,—such markings as are still visible in the rocks of Scandinavia, Scotland, Canada, and many other countries.

There can be no doubt that the myriads of angular and rounded blocks above alluded to cannot have been borne along by ordinary rivers or marine currents, so great is their volume and weight, and so clear are the signs, in many places, of time having been occupied in their successive deposition; for while some of them are buried in mud and sand, others are distributed at various depths through heaps of regularly stratified sand and gravel. No waves of the sea raised by earthquakes, nor the bursting of lakes dammed up for a time by landslips or by avalanches of snow, can account for the observed facts; but I shall endeavour to show, in the sequel,* that a combination of existing causes may have conveyed erratics into their present situations.

* See also Elements of Geology, ch. 11, 12, and Student's Elements, p. 143; et seq.

The causes which will be referred to are, first, the carrying power of ice, combined with that of running water; and second, the upward movement of the bed of the sea, converting it gradually into land. Without entering at present into any details respecting these causes, I may mention that the transportation of blocks by ice is now simultaneously in progress, not only in the arctic and antarctic regions, but in a part of the temperate latitudes both of the northern and southern hemispheres, as, for, example, on the coasts of Canada and Gulf of St. Lawrence, and also in Chili, Patagonia, and the island of South Georgia. In those regions the uneven bed of the ocean is becoming strewed over with ice-drifted fragments, which have either stranded on shoals, or been dropped in deep water by melting bergs. The entanglement of boulders in drift ice will also be shown to occur annually in North America, and these stones, when firmly frozen into ice, wander year after year from Labrador to the St. Lawrence, and reach points of the western hemisphere farther south than any part of Great Britain.

The general absence of erratics in the warmer parts of the equatorial regions of Asia, Africa, and America, confirms the same views. As to the polishing and grooving of hard rocks, it has been ascertained that glaciers give rise to these effects when pushing forward sand, pebbles, and rocky fragments, and causing them to grate along the bottom. Nor can there be any reasonable doubt that icebergs, when they run aground on the floor of the ocean, must imprint somewhat similar marks upon it.

It is unnecessary, therefore, to refer to deluges, or great oceanic waves, to explain the transportation of erratics to great distances.

As to variations in the tides in past times, they can never have been sufficient to have imparted to marine currents, or to the waves breaking on a coast, a degree of force greatly exceeding that which they usually exert. When the excentricity of the earth's orbit, of which more will be said in the thirteenth chapter, is at or near its maximum, the rise of the solar tide will amount to two-and-a-half instead of two feet; but the increased power thus derived

from solar attraction may be neglected by a geologist, seeing that the configuration of the land now produces differences in the height of the tides to the extent of fifty feet and upwards, instead of those few additional inches gained by proximity to the sun in the case above proposed. At some former periods, as we shall afterwards see, the local development of ice, sometimes in one hemisphere, sometimes in the other, was so great as to enable it to exert a carrying power far beyond what it now exerts in the same region. But such increased ice-action, recurring at distant intervals and for limited periods, is by no means confirmatory of the theory of those who ascribe paroxysmal energy to causes supposed to have operated in a nascent state of the planet. In regard also to ice, we must remember that its action on land is substituted for that of running water. The one becomes a mighty agent in transporting huge erratics, and in scoring, abrading, and polishing rocks, but meanwhile the other is in abeyance. When, for example, the ancient Rhone glacier conveyed its moraines from the upper to the lower end of the Lake of Geneva, there was no great river as there now is, forming a delta many miles in extent, and several hundred feet in depth, at the upper end of the lake.

Deluges.—As deluges have been often alluded to (page 10, &c.), I shall say something of the causes which may be supposed to give rise to these grand movements of water.

Geologists who believe that mountain-chains have been thrown up suddenly at many successive epochs, imagine that the waters of the ocean may be raised by these convulsions, and then break in terrific waves upon the land, sweeping over whole continents, hollowing out valleys, and transporting sand, gravel, and erratics to great distances. The sudden rise of the Alps or Andes, it is said, may have produced a flood even subsequently to the time when the earth became the residence of man. But it seems strange that none of the writers who have indulged their imaginations in conjectures of this kind should have ascribed a deluge to the sudden conversion of part of the unfathomable ocean into a shoal rather than to the rise of mountain-chains. In the latter case the mountains themselves could do no

more than displace a certain quantity of atmospheric air, whereas the instantaneous formation of the shoal would displace a vast body of water, which being heaved up to a great height might roll over and permanently submerge a large portion of a continent.

If we restrict ourselves to combinations of causes at present known, it would seem that the two principal sources of extraordinary inundations are, first the escape of the waters of a large lake raised far above the sea; and, secondly, the pouring down of a marine current into lands depressed below the mean level of the ocean.

As an example of the first of these cases, we may take Lake Superior, which is more than 400 geographical miles in length, and about 150 in breadth, having an average depth of from 500 to 900 feet. The surface of this vast body of fresh water is no less than 600 feet above the level of the ocean; the lowest part of the barrier which separates the lake on its south-west side from those streams which flow into the head waters of the Mississippi being about 600 feet high. If, therefore, a series of subsidences should lower any part of this barrier, even a few yards at a time, or if earthquakes should rend it open, the breaches thus made might allow the sudden escape of vast floods of water into a hydrographical basin of enormous extent. If the event happened in the dry season, when the ordinary channels of the Mississippi and its tributaries are in a great degree empty, the inundation might not be considerable; but if in the flood season, a region capable of supporting a population of many millions might be suddenly submerged. But even this event would be insufficient to cause a violent rush of water, and to produce those effects usually called diluvial; for the difference of level of 600 feet between Lake Superior and the Gulf of Mexico, when distributed over a distance of 1,800 miles, would give an average fall of only four inches per mile.

The second case before adverted to is where there are large tracts of dry land beneath the mean level of the ocean. It seems, after much controversy, to be at length a settled point, that the Caspian is really 83 feet 6 inches lower than the Black Sea. As the Caspian covers an area about equal

to that of Spain, and as its shores are in general low and flat, there must be many thousand square miles of country less than 83 feet above the level of that inland sea, and consequently depressed below the Black Sea and Mediterranean. This area includes the site of the populous city of Astrakhan and other towns. Into this region the ocean would pour its waters, if the land now intervening between the Black Sea (or rather the Sea of Azof) and the Caspian should subside. Yet, even if this event should occur, it is most probable that the submergence of the whole region would not be accomplished simultaneously, but by a series of minor floods, the sinking of the barrier being gradual.* The shores of the Dead Sea have lately been ascertained by a party of our Royal Engineers to be about 1,300 English feet below the level of the Mediterranean, or about four feet less than 1,300 on an average.† In this case, towns built on hills nearly 1,300 feet high might be submerged by such a change of level in the barrier as would open a communication between the Mediterranean and the valley of the Jordan.

Supposed universality of ancient deposits.—The next fallacy which has helped to perpetuate the doctrine that the operations of water were on a different and grander scale in ancient times is founded on the indefinite areas over which homogeneous deposits were supposed to extend. No modern sedimentary strata, it was said, equally identical in mineral character and fossil contents, can be traced continuously from one quarter of the globe to another. But the first propagators of these opinions were very slightly acquainted with the inconstancy in mineral composition of the ancient

* It has been suspected ever since the middle of the last century, that the Caspian was lower than the ocean, it being known that in Astrakhan the mercury in the barometer generally stands above thirty inches. In 1836, the Russian government directed the Academy of St. Petersburg to send an expedition to determine the relative level of the Caspian and Black Seas by a trigonometrical survey. It was found that the Caspian was 101 Russian, or 108 English, feet lower than the Black Sea. (For authorities, see Journ. Roy. Geograph. Soc. vol. viii. p. 135.) Sir R. Murchison, however, concludes, in 1845, from the best Russian authorities, that the depression of the Caspian is only 83 feet 6 inches.

† Sir Henry James, who planned this survey, which was executed by Capt. Wilson, R.E., informs me that on the 12th of March, 1865, the difference of level was 1,292 feet. The maximum depression occurring in the dry season amounts to 1,298 feet, the minimum, as ascertained by the drifted seaweed on the shores, being only 1,289·5 feet.

formations, and equally so of the wide spaces over which the same kind of sediment is now actually distributed by rivers and currents in the course of centuries. The persistency of character in the older series was exaggerated, its extreme variability in the newer was assumed without proof. In the chapter which treats of river-deltas and the dispersion of sediment by currents, and in the description of reefs of coral now growing over areas many hundred miles in length, I shall have opportunities of convincing the reader of the danger of hasty generalisations on this head. I may also mention in this place, that the vast distance to which the white chalk can be traced east and west over Europe, as well as north and south, from Denmark to the Crimea, seemed to some geologists a phenomenon, to which the working of causes now in action could present no parallel. But the soundings made in the Atlantic for the submarine telegraph have taught us that white mud, formed of organic bodies similar to those of the ancient chalk, is in progress over spaces still more vast.*

But in regard to the imagined universality of particular rocks of ancient date, it was almost unavoidable that this notion, when once embraced, should be perpetuated; for the same kinds of rock have occasionally been reproduced at successive epochs: and when once the agreement or disagreement in mineral character alone was relied on as the test of age, it followed that similar rocks, if found even at the antipodes, were referred to the same era, until the contrary could be shown.

Now it is usually impossible to combat such an assumption on geological grounds, so long as we are imperfectly acquainted with the order of superposition and the organic remains of these same formations. Thus, for example, the red marl and red sandstone, containing salt and gypsum (the Triassic group of the table, p. 135), being interposed in England between the Lias and the Coal, all other red marls and sandstones, associated some of them with salt, and others with gypsum, and occurring not only in different parts of Europe, but in North America, Peru, India, the salt deserts of Asia,

* Elements of Geol., 6th edit. p. 318; and Student's Elements, p. 261.

those of Africa—in a word, in every quarter of the globe—were referred to one and the same period. The burden of proof was not supposed to rest with those who insisted on the identity in age of all these groups—their identity in mineral composition was thought sufficient. It was in vain to urge as an objection the improbability of the hypothesis which implies that all the moving waters on the globe were once simultaneously charged with sediment of a red colour.

But the rashness of pretending to identify, in age, all the red sandstones and marls in question, has at length been sufficiently exposed, by the discovery that, even in Europe, they belong decidedly to many different epochs. The investigations of De Verneuil in Spain have shown that the red sandstone and red marl, containing the rock salt of Cardona in Catalonia, belong to the Middle Eocene or Nummulitic period. It is also known that certain red marls and variegated sandstones in Auvergne which are undistinguishable in mineral composition from the New Red Sandstone of English geologists, are nevertheless of the same older tertiary period: and, lastly, the gypseous red marl of Aix, in Provence, formerly supposed to be a marine secondary group, is now acknowledged to be a tertiary fresh-water formation. In Nova Scotia one great deposit of red marl, sandstone, and gypsum, precisely resembling in mineral character the 'New Red' of England, occurs as a member of the Carboniferous group, and in the United States near the Falls of Niagara, a similar formation constitutes a subdivision of the Upper Silurian series.*

Nor was the nomenclature commonly adopted in geology without its influence in perpetuating the erroneous doctrine of universal formations. Such names, for example, as Chalk, Greensand, Oolite, Red Marl, Coal, and others, were given to some of the principal fossiliferous groups in consequence of mineral peculiarities which happened to characterise them in the countries where they were first studied. When geologists had at length shown, by means of fossils and the order of superposition, that other strata, entirely dissimilar in colour, texture, and composition, were of contemporaneous

* See Lyell's Travels in N. America, ch. 2 and 25.

date, it was thought convenient still to retain the old names. That these were often inappropriate was admitted; but the student was taught to understand them in no other than a chronological sense; so that the Chalk might be a grey quartzose sandstone devoid of calcareous matter, as near Dresden, or a hard, compact, and sometimes flaggy limestone, as in parts of the Alps, or a brown sandstone or green marl, as in New Jersey, U.S. In like manner, the Greensand, it was said, is often represented by limestone and other mineral masses entirely devoid of green grains. So the Oolitic texture was declared to be rather an exception than otherwise to the general rule in rocks of the Oolitic period, and to be found in strata both of older and newer date; and it often became necessary to affirm that no particle of carbonaceous matter could be detected in districts where the true Coal series abounded. In spite of every precaution, the habitual use of this language could scarcely fail to instil into the mind of the pupil an idea that chalk, coal, salt, red marl, and the Oolitic structure were far more widely characteristic of the rocks of a given age than was really the case.

There is still another cause of deception, disposing us to ascribe a more limited range to the newer sedimentary formations as compared to the older, namely, the very general concealment of the newer strata beneath the waters of lakes and seas, and the wide exposure above waters of the more ancient. The Chalk, for example, now seen stretching for thousands of miles over different parts of Europe, has become visible to us by the effect, not of one, but of many distinct series of subterranean movements. Time has been required, and a succession of geological periods, to raise it above the waves in so many regions; and if calcareous rocks of the middle and upper tertiary periods have been formed, as homogeneous in mineral composition throughout equally extensive regions, it may require convulsions as numerous as all those which have occurred since the origin of the Chalk to bring them up within the sphere of human observation. Hence the rocks of more modern periods may appear partial, as compared to those of remoter eras, not because of any original inferiority in their extent, but because there has not

been sufficient time since their origin for the development of a great series of elevatory movements.

In regard, however, to one of the most important characteristics of sedimentary rocks, their organic remains, many naturalists of high authority have maintained that the same species of fossils are more widely distributed through formations of high antiquity than in those of more modern date, and that distinct zoological and botanical provinces, as they are called, which form so striking a feature in the living creation, were not established at remote eras. Thus the plants of the Coal, the shells and trilobites of the Silurian rocks, and the ammonites of the Oolite, have been supposed to have a wider geographical range than any living species of plants, crustaceans, or mollusks. This opinion seems in certain cases to be well founded, especially in relation to the plants of the Carboniferous epoch, owing partly to greater uniformity of climate, and partly, as Professor Heer has suggested, to the fact that almost all the plants—including even large trees—of that period, were cryptogamous: so that their minute spores might be carried by the wind for indefinite distances, as are now the spores of ferns, mosses, and lichens. But a recent comparison of the fossils of North American rocks with those of corresponding ages in the European series, has proved that the terrestrial vegetation of the Carboniferous epoch is an exception to the general rule, and that the fauna and flora of the earth at successive periods, from the oldest Silurian to the newest Tertiary, were as diversified as now. The shells, corals, and other classes of organic remains demonstrate the fact that the earth might then have been divided into separate zoological provinces, in a manner analogous to that observed in the geographical distribution of species now living.

CHAPTER VII.

ON THE SUPPOSED FORMER INTENSITY OF THE IGNEOUS FORCES.

VOLCANIC ACTION AT SUCCESSIVE GEOLOGICAL PERIODS—PLUTONIC ROCKS OF DIFFERENT AGES—GRADUAL DEVELOPMENT OF SUBTERRANEAN MOVEMENTS—FAULTS—DOCTRINE OF THE SUDDEN UPHEAVAL OF PARALLEL MOUNTAIN-CHAINS—OBJECTIONS TO THE PROOF OF THE SUDDENNESS OF THE UPHEAVAL, AND THE CONTEMPORANEOUSNESS OF PARALLEL CHAINS—TRAINS OF ACTIVE VOLCANOS NOT PARALLEL—AS LARGE TRACTS OF LAND ARE RISING OR SINKING SLOWLY, SO NARROW ZONES OF LAND MAY BE PUSHED UP GRADUALLY TO GREAT HEIGHTS—BENDING OF STRATA BY LATERAL PRESSURE—ADEQUACY OF THE VOLCANIC POWER TO EFFECT THIS WITHOUT PAROXYSMAL CONVULSIONS.

WHEN reasoning on the intensity of volcanic action at former periods, as well as on the power of moving water, geologists have been ever prone to represent Nature as having been prodigal of violence and parsimonious of time. Now, although it is less easy to determine the relative ages of the volcanic than of the fossiliferous formations, it is undeniable that igneous rocks have been produced at all geological periods, or as often as we find distinct deposits marked by peculiar animal and vegetable remains. It can be shown, for example, that there are not only trappean rocks contemporaneous with the Palæozoic, Mesozoic, and Cainozoic periods, and with each of the several groups into which these are divisible, but that volcanic products can be more strictly limited and assigned to minor subdivisions, such as the Lower and Upper Carboniferous and the Lower and Upper Eocene. Again, if one of these igneous formations is examined in detail, we find it to be the product of many successive ejections or outpourings of volcanic matter.* As we enlarge,

* See Elements of Geology, 6th ed.; and Student's Elements, 1871. Index, 'Volcanic.'

therefore, our knowledge of the ancient rocks formed by subterranean heat, we find ourselves compelled to regard them as the aggregate effects of innumerable eruptions, each of which may have been comparable in violence to those now experienced in volcanic regions.

It may indeed be said that we have as yet no data for estimating the relative volume of matter simultaneously in a state of fusion at two given periods, as if we were to compare the columnar basalt of Staffa and its environs with the lava poured out in Iceland in 1783; and for this very reason it would be rash and unphilosophical to assume an excess of ancient as contrasted with modern outpourings of melted matter at particular periods of time.* It would be still more presumptuous to take for granted that the more deep-seated effects of subterranean heat surpassed at remote eras the corresponding effects of internal heat in our own times. Certain porphyries and granites, and all the rocks commonly called plutonic, are now generally supposed to have resulted from the slow cooling of materials fused and solidified under great pressure; and we cannot doubt that beneath existing volcanos there are large spaces filled with melted stone, which must for centuries remain in an incandescent state, and then cool and become hard and crystalline. That lakes of lava are continuous for hundreds of miles beneath the Chilian Andes, seems established by observations made in the year 1835.†

Now, wherever the fluid contents of such reservoirs are poured out successively from craters in the open air, or at the bottom of the sea, the matter so ejected may afford evidence by its arrangement of having originated at different periods; but if the subterranean residue after the withdrawal of the heat be converted into crystalline or plutonic rock, the entire mass may seem to have been formed at once, however countless the ages required for its fusion and subsequent refrigeration. As the idea that all the granite in the earth's crust was produced simultaneously, and in a primitive state of the planet, has now been universally abandoned; so the

* See below, vol. ii., Icelandic eruptions.
† See below, vol. ii., Chilian earthquake.

suggestion above adverted to may put us on our guard against too readily adopting another opinion, namely, that each large mass of granite was generated in a brief period of time. Indeed, modern writers of authority seem more and more agreed that in the case of granitic rocks, the passage from a liquid or pasty to a solid and crystalline state must have been an extremely gradual process.

The doctrine so much insisted upon formerly, that crystalline rocks, such as granite, gneiss, mica-schist, quartzite, and others, were produced in the greatest abundance in the earlier ages of the planet, and that their formation has ceased altogether in our own times, will be controverted in the next chapter.

Gradual development of subterranean movements.—The extreme violence of the subterranean forces in remote ages has been often inferred from the fact that the older rocks are more fractured and dislocated than the newer. But what other result could we have anticipated if the quantity of movement had been always equal in equal periods of time? Time must, in that case, multiply the derangement of strata in the ratio of their antiquity. Indeed the numerous exceptions to the above rule which we find in nature, present at first sight the only objection to the hypothesis of uniformity. For the more ancient formations remain in many places horizontal, while in others much newer strata are curved and vertical. This apparent anomaly, however, will be seen in the next chapter to depend on the irregular manner in which the volcanic and subterranean agencies affect different parts of the earth in succession, being often renewed again and again in certain areas, while others remain during the whole time at rest.

That the more impressive effects of subterranean power, such as the upheaval of mountain-chains, may have been due to multiplied convulsions of moderate intensity rather than to a few paroxysmal explosions, will appear the less improbable when the gradual and intermittent development of volcanic eruptions in times past is once established, for geologists no longer doubt that there is an intimate connection between the two classes of phenomena.

Faults.—The same reasoning is applicable to great *faults*, or those striking instances of the upthrow or downthrow of large masses of rock, which have been thought by some to imply tremendous catastrophes wholly foreign to the ordinary course of nature. Thus we have in England faults in which the vertical displacement of the rocks amounts sometimes to several hundred, and in other cases to several thousand feet, while the fissures extend horizontally for distances varying from a few hundred yards to thirty miles. Their width varies from less than an inch to fifty feet, the space between the opposite walls being now filled up with fragmentary matter from the sides, and various minerals which have crystallised along the fissures. But when we enquire into the proofs of the mass having risen or fallen suddenly on the one side of these great rents, several hundreds or thousands of feet above or below the rock with which it was once continuous on the other side, we find the evidence defective. There are grooves, it is said, and scratches on the rubbed and polished walls which have often one common direction, favouring the theory that the movement was accomplished by a single stroke, and not by a series of interrupted movements. But, in fact, the striæ are not always parallel in such cases, but often irregular, and sometimes the stones and earth which are in the middle of the fault, or fissure, have been polished and striated by friction in different directions, showing that there have been slidings subsequent to the first introduction of the fragmentary matter. Nor should we forget that the last movement must always tend to obliterate the signs of previous trituration, so that neither its instantaneousness nor the uniformity of its direction can be inferred from the parallelism of the striæ that have been last produced.

When rocks have been once fractured, and freedom of motion communicated to detached portions of them, these will naturally continue to yield in the same direction, if the process of upheaval or of undermining be repeated again and again. The incumbent mass will always give way along the lines of least resistance, and therefore usually in the places where it was formerly rent asunder. Probably the effects of

reiterated movement, whether upward or downward, in a fault, may be undistinguishable from those of a single and instantaneous rise or subsidence; and the same may be said of the rising or falling of continental masses, such as Sweden or Greenland, which we know to take place slowly and insensibly.

Doctrine of the sudden upheaval of parallel mountain-chains.—The doctrine of the suddenness of many former revolutions in the physical geography of the globe has been thought by some to derive additional confirmation from a theory respecting the origin of mountain-chains, advanced in 1833 by a distinguished geologist, M. Elie de Beaumont. In several essays on this subject, the last published in 1852, he has attempted to establish two points; first, that a variety of independent chains of mountains have been thrown up suddenly at particular periods; and, secondly, that the contemporaneous chains thus thrown up preserve a parallelism the one to the other.

These opinions, and others by which they are accompanied, are so adverse to the method of interpreting the history of geological changes which I have recommended in this work, that I am desirous of explaining the grounds of my dissent, a course which I feel myself the more called upon to adopt, as the generalisations alluded to have been very popular, owing to the known experience of the author as an observer in the field, his profound mathematical acquirements, and his skill as a writer. I shall begin, therefore, by giving a brief summary of the principal propositions laid down in the works above referred to.*

1st. M. de Beaumont supposes 'that in the history of the earth there have been long periods of comparative repose, during which the deposition of sedimentary matter has gone on in regular continuity; and there have also been short periods of paroxysmal violence, during which that continuity was broken.

* Ann. des Sci. nat., septembre, novembre, et décembre 1829. Revue Française, No. 15. May 1830. Bulletin de la Société Géol. de France, p. 864. May 1847. The latest edition of M. de Beaumont's theory will be found in the 12th vol. of the Dictionnaire universelle d'Hist. nat. 1852, art. 'Systèmes de Montagnes;' also the same printed separately.

'2dly. At each of these periods of violence or "revolution," in the state of the earth's surface, a great number of mountain-chains have been formed suddenly.

'3dly. The chains thrown up by a particular revolution have one uniform direction, being parallel to each other within a few degrees of the compass, even when situated in remote regions; whilst the chains thrown up at different periods differ, for the most part, from each other in direction.

'4thly. Each "revolution," or "great convulsion," has fallen in with the date of another geological phenomenon; namely, "the passage from one independent sedimentary formation to another," characterised by a considerable difference in "organic types."

'5thly. There has been a recurrence of these paroxysmal movements from the remotest geological periods; and they may still be reproduced, and the repose in which we live may hereafter be broken by the sudden upthrow of another system of parallel chains of mountains.

'6thly. The origin of these chains depends not on partial volcanic action, or a reiteration of ordinary earthquakes, but on the secular refrigeration of the entire planet. For the whole globe, with the exception of a thin envelope, much thinner in proportion than the shell to an egg, is a fused mass, kept fluid by heat, but constantly cooling and contracting its dimensions. The external crust does not gradually collapse and accommodate itself century after century to the shrunken nucleus, subsiding as often as there is a slight failure of support, but it is sustained throughout whole geological periods, so as to become partially separated from the nucleus, until at last it gives way suddenly, cracking and falling in along determinate lines of fracture. During such a crisis the rocks are subjected to great lateral pressure, the unyielding ones are crushed, and the pliant strata bent, and are forced to pack themselves more closely into a smaller space, having no longer the same room to spread themselves out horizontally. At the same time, a large portion of the mass is squeezed upwards, because it is in the upward direction only that the excess in size of the envelope, as compared to the contracted nucleus, can find relief. This excess

produces one or more of those folds or wrinkles in the earth's crust which we call mountain-chains.

'Lastly, some chains are comparatively modern; such as the Alps, which were partly upheaved after the middle tertiary period. The elevation of the Andes was much more recent, and was accompanied by the simultaneous outburst for the first time of 270 of the principal volcanos now active.* The agitation of the waters of the ocean caused by this convulsion probably occasioned that transient and general deluge which is noticed in the traditions of so many nations.' †

Several of the topics enumerated in the above summary, such as the cause of interruptions in the sedimentary series, will be discussed in the 14th chapter, and I shall now confine myself to what I conceive to be the insufficiency of the proofs adduced in favour of the suddenness of the upthrow, and the contemporaneousness of the origin of the parallel chains referred to. At the same time I may remark, that the great body of facts collected together by M. de Beaumont will always form a most valuable addition to our knowledge, tending as they do to confirm the doctrine that different mountain-chains have been formed in succession, and, as Werner first pointed out, that there are certain determinate lines of direction or strike in the strata of various countries.

The following may serve as an analysis of the evidence on which the theory above stated depends. 'We observe,' says M. de Beaumont, 'when we attentively examine nearly all mountain-chains, that the most recent rocks extend horizontally up to the foot of such chains, as we should expect would be the case if they were deposited in seas or lakes, of which these mountains have partly formed the shores; whilst the other sedimentary beds, tilted up, and more or less contorted, on the flanks of the mountains, rise in certain points even to their highest crests.' ‡ There are, therefore, in and adjacent to each chain, two classes of sedimentary rocks, the ancient or inclined beds, and the newer or horizontal. It is evident that the first appearance of the chain itself was an

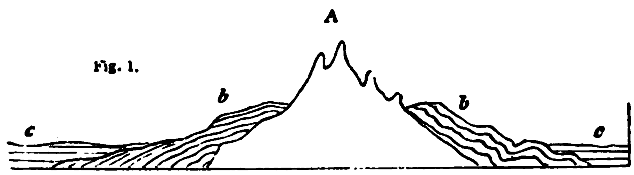
* Systèmes de Montagnes, p. 762.

† Ibid. pp. 761 and 773.

‡ Phil. Mag. and Annals, No. 58. New Series, p. 242.

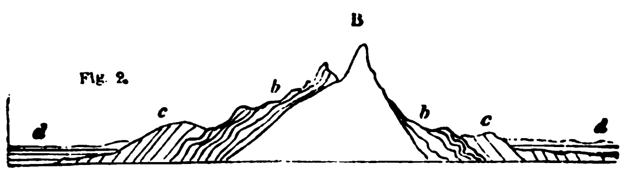
event 'intermediate between the period when the beds now upraised were deposited, and the period when the strata were produced horizontally at its feet.'

Thus the chain A assumed its present position after the



deposition of the strata *b*, which have undergone great movements, and before the deposition of the group *c*, in which the strata have not suffered derangement.

If we then discover another chain B, in which we find not



only the formation *b*, but the group *c* also, disturbed and thrown on its edges, we may infer that the latter chain is of subsequent date to A; for B must have been elevated *after* the deposition of *c*, and before that of the group *d*; whereas A had originated *before* the strata *c* were formed.

It is then argued, that in order to ascertain whether other mountain-ranges are of contemporaneous date with A and B, or are referable to *distinct* periods, we have only to enquire whether the inclined and undisturbed sets of strata in each range correspond with or differ from those in the typical chains A and B.

Now all this reasoning is perfectly correct so long as the period of time required for the deposition of the strata *b* and *c* respectively is not made identical in duration with the period of time during which the animals and plants found fossil in *b* and *c* may have flourished; for the duration of certain groups of species may have greatly exceeded, and probably did greatly exceed, the time required for the

accumulation of certain local deposits, such as *b* and *c* (figs. 1 and 2). In order, moreover, to render the reasoning correct, due latitude must be given to the term contemporaneous; for this term must be understood to allude, not to a moment of time, but to the interval, whether brief or protracted, which elapsed between two events, namely, between the accumulation of the inclined and that of the horizontal strata.

But, unfortunately, no attempt has been made in the treatises under review to avoid this manifest source of confusion, and hence the very terms of each proposition are equivocal; and the possible length of some of the intervals is so vast, that to affirm that all the chains raised in such intervals were *contemporaneous* is an abuse of language.

In order to illustrate this argument, I shall select the Pyrenees as an example. Originally M. E. de Beaumont spoke of this range of mountains as having been uplifted suddenly (*à un seul jet*), but he has since conceded that in this chain, in spite of the general unity and simplicity of its structure, six, if not seven, systems of dislocation of different dates can be recognised.* In reference, however, to the latest, and by far the most important of these convulsions, the chain is said to have attained its present elevation at a certain epoch in the earth's history, namely, between the deposition of the chalk, or rocks of about that age, and that of certain tertiary formations 'as old as the plastic clay;' for the chalk is seen in vertical, curved, and distorted beds on the flanks of the chain, as the beds *b*, fig. 1, while the tertiary formations rest upon them in horizontal strata at its base, as *c*, ibid.

The proof, then, of the extreme suddenness of the convulsion is supposed to be the shortness of the time which intervened between the formation of the chalk and the origin of certain tertiary strata.† Even if the interval were reducible within these limits, it might comprise an indefinite lapse of time. In strictness of reasoning, however, the author cannot exclude the Cretaceous or the Tertiary periods

* Systèmes de Montagnes, 1852, p. 429.

† Phil. Mag. and Annals, No. 58 New Series, p. 243.

from the possible duration of the interval during which the elevation may have taken place, for, in the first place, it cannot be assumed that the movement of upheaval took place after the close of the Cretaceous period; we can merely say, that it occurred after the deposition of certain strata of that period; secondly, although it were true that the event happened before the formation of all the tertiary strata now at the base of the Pyrenees, it would by no means follow that it preceded the whole Tertiary epoch.

The age of the strata, both of the inclined and horizontal series, may have been accurately determined by M. de Beaumont, and still the upheaving of the Pyrenees may have been going on before the animals of the Chalk period, such as are found fossil in England, had ceased to exist, or when the Maestricht beds were in progress, or during the indefinite ages which may have elapsed between the extinction of the Maestricht animals and the introduction of the Eocene tribes, or during the Eocene epoch, or the rise may have been going on throughout one, or several, or all of these periods.

It would be a purely gratuitous assumption to say that the inclined cretaceous strata (*b*, fig. 1) on the flanks of the Pyrenees, were the very last which were deposited during the Cretaceous period, or that as soon as they were upheaved all or nearly all the species of animals and plants now found fossil in them were suddenly exterminated; yet, unless this can be affirmed, we cannot say that the Pyrenees were not upheaved during the Cretaceous period. Consequently, another range of mountains, at the base of which cretaceous rocks may lie in horizontal stratification, may have been elevated, like the chain A, fig. 1, during some part of the same great period.

There are mountains in Sicily two or three thousand feet high, the tops of which are composed of limestone, in which a large proportion of the fossil shells agree specifically with those now inhabiting the Mediterranean. Here, as in many other countries, the deposits now in progress in the sea must inclose shells and other fossils specifically identical with those of the rocks constituting the contiguous land. So

there are islands in the Pacific, where a mass of dead coral has emerged to a considerable altitude, while other portions of the mass remain beneath the sea, still increasing by the growth of living zoophytes and shells. The chalk of the Pyrenees, therefore, may at a remote period have been raised to an elevation of several thousand feet, while the species found fossil in the same chalk still continued to be represented in the fauna of the neighbouring ocean. In a word, we cannot assume that the origin of a new range of mountains caused the Cretaceous period to cease, and served as the prelude to a new order of things in the animate creation.

To illustrate the grave objections above advanced, against the theory considered in the present chapter, let us suppose, that in some country three styles of architecture had prevailed in succession, each for a period of one thousand years; first the Greek, then the Roman, and then the Gothic; and that a tremendous earthquake was known to have occurred in the same district during one of the three periods—a convulsion of such violence as to have levelled to the ground all the buildings then standing. If an antiquary, desirous of discovering the date of the catastrophe, should first arrive at a city where several Greek temples were lying in ruins and half engulphed in the earth, while many Gothic edifices were standing uninjured, could he determine on these data the era of the shock? Could he even exclude any one of the three periods, and decide that it must have happened during one of the other two? Certainly not. He could merely affirm that it happened at some period after the introduction of the Greek style, and before the Gothic had fallen into disuse. Should he pretend to define the date of the convulsion with greater precision, and decide that the earthquake must have occurred after the Greek and before the Gothic period, that is to say, when the Roman style was in use, the fallacy in his reasoning would be too palpable to escape detection for a moment.

Yet such is the nature of the erroneous induction of which I am now treating. For as, in the example above proposed, the erection of a particular edifice is an event scarcely ever coextensive in time with the whole period of a certain style

of architecture to which it conformed, so the deposition of chalk or any other set of strata may have been effected in a small part of that geological epoch to which the species of fossils characterising such strata may belong.

It is almost superfluous to enter into any further analysis of the theory of parallelism, because the whole force of the argument depends on the accuracy of the data by which the contemporaneous or non-contemporaneous date of the elevation of two independent chains can be demonstrated. In every case, this evidence, as stated by M. de Beaumont, is equivocal, because he has not included in the possible interval of time between the deposition of the deranged and the horizontal formations, part of the periods to which each of those classes of formations are referable. Even if all the geological facts, therefore, adduced by the author were true and unquestionable, yet the conclusion that certain chains were or were not simultaneously upraised is by no means a legitimate consequence.

In the third volume of my first edition of the Principles, which appeared in April 1833, I controverted the views of M. de Beaumont, then just published, in the same terms as I have now restated them. At that time I took for granted that the chronological date of the newest rocks entering into the disturbed series of the Pyrenees had been correctly ascertained. It now appears, however, that some of the most modern of those disturbed strata belong to the nummulitic formation, which are now regarded by the majority of geologists as Eocene or lower tertiary.

Perhaps a more striking illustration of the difficulties we encounter, when we attempt to apply the theory under consideration even to the best known European countries, is afforded by what is called by de Beaumont 'The System of the Longmynds.' This small chain, situated in Shropshire, and having a direction of N. 25° E., is the third of the typical systems to which other mountain-ranges corresponding in *strike* and structure are compared. The date assigned to its upheaval is 'after the unfossiliferous greywacke, or Cambrian strata, and before the Silurian.' But Sir R. I. Murchison had shown in 1838, in his 'Silurian System,' and the British

suggestion above adverted to may put us on our guard against too readily adopting another opinion, namely, that each large mass of granite was generated in a brief period of time. Indeed, modern writers of authority seem more and more agreed that in the case of granitic rocks, the passage from a liquid or pasty to a solid and crystalline state must have been an extremely gradual process.

The doctrine so much insisted upon formerly, that crystalline rocks, such as granite, gneiss, mica-schist, quartzite, and others, were produced in the greatest abundance in the earlier ages of the planet, and that their formation has ceased altogether in our own times, will be controverted in the next chapter.

Gradual development of subterranean movements.—The extreme violence of the subterranean forces in remote ages has been often inferred from the fact that the older rocks are more fractured and dislocated than the newer. But what other result could we have anticipated if the quantity of movement had been always equal in equal periods of time? Time must, in that case, multiply the derangement of strata in the ratio of their antiquity. Indeed the numerous exceptions to the above rule which we find in nature, present at first sight the only objection to the hypothesis of uniformity. For the more ancient formations remain in many places horizontal, while in others much newer strata are curved and vertical. This apparent anomaly, however, will be seen in the next chapter to depend on the irregular manner in which the volcanic and subterranean agencies affect different parts of the earth in succession, being often renewed again and again in certain areas, while others remain during the whole time at rest.

That the more impressive effects of subterranean power, such as the upheaval of mountain-chains, may have been due to multiplied convulsions of moderate intensity rather than to a few paroxysmal explosions, will appear the less improbable when the gradual and intermittent development of volcanic eruptions in times past is once established, for geologists no longer doubt that there is an intimate connection between the two classes of phenomena.

Faults.—The same reasoning is applicable to great *faults*, or those striking instances of the upthrow or downthrow of large masses of rock, which have been thought by some to imply tremendous catastrophes wholly foreign to the ordinary course of nature. Thus we have in England faults in which the vertical displacement of the rocks amounts sometimes to several hundred, and in other cases to several thousand feet, while the fissures extend horizontally for distances varying from a few hundred yards to thirty miles. Their width varies from less than an inch to fifty feet, the space between the opposite walls being now filled up with fragmentary matter from the sides, and various minerals which have crystallised along the fissures. But when we enquire into the proofs of the mass having risen or fallen suddenly on the one side of these great rents, several hundreds or thousands of feet above or below the rock with which it was once continuous on the other side, we find the evidence defective. There are grooves, it is said, and scratches on the rubbed and polished walls which have often one common direction, favouring the theory that the movement was accomplished by a single stroke, and not by a series of interrupted movements. But, in fact, the striæ are not always parallel in such cases, but often irregular, and sometimes the stones and earth which are in the middle of the fault, or fissure, have been polished and striated by friction in different directions, showing that there have been slidings subsequent to the first introduction of the fragmentary matter. Nor should we forget that the last movement must always tend to obliterate the signs of previous trituration, so that neither its instantaneousness nor the uniformity of its direction can be inferred from the parallelism of the striæ that have been last produced.

When rocks have been once fractured, and freedom of motion communicated to detached portions of them, these will naturally continue to yield in the same direction, if the process of upheaval or of undermining be repeated again and again. The incumbent mass will always give way along the lines of least resistance, and therefore usually in the places where it was formerly rent asunder. Probably the effects of

In a portion of this latter period the 'Pampean mud' was formed, in which the Megatherium, Mylodon, and other extinct quadrupeds are buried. This mud contains in it recent species of shells, some of them proper to brackish water, and is believed by Mr. Darwin to be an estuary or delta deposit.

In studying many chains of mountains, we find that the strike or line of outcrop of continuous sets of strata, and the general direction of the chain, may be far from rectilinear. It may even deviate from the normal direction at an angle of 20° or 30°, as is exemplified in the Alleghanies.* In like manner, trains of active volcanos and the zones throughout which modern earthquakes occur are often linear, but though contemporaneous, all belonging to our own epoch, they are not by any means parallel, but some at right angles, the one to the other.

Slow upheaval and subsidence.—Recent observations have disclosed to us the wonderful fact, that not only the west coast of South America, but also other large areas, some of them several thousand miles in circumference, such as Scandinavia, and certain archipelagos in the Pacific, are slowly and insensibly rising; while other regions, such as Greenland, and parts of the Pacific and Indian oceans, in which atolls or circular coral islands abound, are as gradually sinking. That all the existing continents and submarine abysses may have originated in movements of this kind, continued throughout incalculable periods of time, is undeniable, for marine remains are found in rocks at almost all elevations above the sea, and the denudation which the dry land appears to have suffered, favours the idea that it was raised from the deep by movements of the earth's crust, prolonged throughout indefinite periods. Rain and rivers, aided sometimes by slow and sometimes by sudden and violent movements, have undoubtedly excavated some of the principal valleys; but there are also wide spaces which have been denuded in such a manner as can only be explained by reference to the action of waves and currents on land slowly emerging from the deep.

* See Student's Elements, p. 70.

It may perhaps be said that there is no analogy between the slow upheaval of broad plains or table lands, and the manner in which we must presume all mountain-chains, with their inclined strata, to have originated. It seems, however, that the Andes have been rising century after century, at the rate of several feet, while the Pampas on the east have been raised only a few inches in the same time. Crossing from the Atlantic to the Pacific, in a line passing through Mendoza, Mr. Darwin traversed a plain 800 miles broad, the eastern part of which has emerged from beneath the sea at a very modern period. The slope from the Atlantic is at first very gentle, then greater, until the traveller finds, on reaching Mendoza, that he has gained, almost insensibly, a height of 4,000 feet. The mountainous district then begins suddenly, and its breadth from Mendoza to the shores of the Pacific is 120 miles, the average height of the principal chain being from 15,000 to 16,000 feet, without including some prominent peaks which ascend much higher. Now all we require, to explain the origin of the principal inequalities of level here described, is to imagine, first a zone of more violent movement to the west of Mendoza, and, secondly, to the east of that place, an upheaving force, which died away gradually as it approached the Atlantic. In short, we are only called upon to conceive, that the region of the Andes was pushed up four feet in the same period in which the Pampas near Mendoza rose one foot, and the plains near the shores of the Atlantic one inch. In Europe the land at the North Cape is said to ascend about five feet in a century; farther to the south, as at Gefle, it amounts to two or three feet in the same period, while at Stockholm it does not exceed three or four inches, and at certain points still farther south there is no movement.

But in what manner, it is asked, can we account for the great lateral pressure which has been exerted, not only in the Andes, Alps, and other chains, but also on the strata of many low and nearly level countries? Do not the folding and fracture of the beds, the anticlinal and synclinal ridges and troughs, as they are called, and the vertical, and even sometimes the inverted position of the beds, imply an abruptness

and intensity in the disturbing force wholly different in kind and energy to that which now rends the rocks during ordinary earthquakes? I shall treat more fully in the second volume of the probable subterranean sources, whether of upward or downward movement, and of great lateral pressure, but it may be well briefly to state in this place that in our own times, as, for example, in Chili, in 1822, the volcanic force has overcome the resistance, and permanently uplifted a country of such vast extent that the weight and volume of the Andes must be insignificant in comparison, even if we indulge the most moderate conjectures as to the thickness of the earth's crust above the volcanic foci.

To assume that any set of strata with which we are acquainted are made up of such cohesive and unyielding materials as to be able to resist a power of such stupendous energy, if its direction, instead of being vertical, happened to be oblique or horizontal, would be extremely rash. But if they could yield to a sideway thrust, even in a slight degree, they would become squeezed and folded to any amount if subjected for a sufficient number of times to the repeated action of the same force. We can scarcely doubt that a mass of rock several miles thick was uplifted in Chili in 1822 and 1835, and that a much greater volume of solid matter is upheaved wherever the rise of land is very gradual, as in Scandinavia, the development of heat being probably, in that region, at a greater distance from the surface. If continents, rocked, shaken and fissured, like the western region of South America, or very gently elevated, like Norway and Sweden, do not acquire in a few days or hours an additional height of several thousand feet, this can arise from no lack of mechanical force in the subterranean moving cause. It must arise simply from the antagonist forces having previously become nearly or quite balanced, those of expansion and resistance having approached an equilibrium. The incumbent crust of the earth is never allowed to attain that strength and coherence which would be necessary in order to enable the volcanic force to accumulate and form an explosive charge capable of producing a grand paroxysmal eruption. The subterranean power, on the contrary, displays

even in its most energetic efforts an intermittent and mitigated intensity, being never permitted to lay a whole continent in ruins. Hence the numerous eruptions of lava from the same vent, or chain of vents, and the recurrence of similar earthquakes for thousands of years along certain areas or zones of country. Hence the numerous monuments of the successive ejection and injection of melted matter in ancient geological epochs, and the fissures formed in distinct ages, and often widened and filled at different eras.

Among the causes of lateral pressure, the expansion by heat of large masses of solid stone intervening between others which have a different degree of expansibility, or which happen not to have their temperature raised at the same time, may play an important part. It may also happen that hot vapours or thermal waters charged with various mineral matters in solution, may permeate rocks and augment their volume, while giving rise to new chemical combinations and a metamorphic structure. We shall presently see, when treating of the great thickness of shallow-water deposits of different geological periods, how repeatedly some areas have sunk down hundreds or thousands of feet below their original level, and we can hardly doubt that much of the bending of pliant strata, and the packing of the same into smaller spaces, has taken place during such subsidence. Whether the failure of support be produced by the melting of porous rocks, which, when fluid, and subjected to great pressure, may occupy less room than before, or which, by passing from a pasty to a crystalline condition, may, as in the case of granite, suffer contraction, or whether the sinking be due to the subtraction of lava driven elsewhere to some volcanic orifice, and there forced outwards, or whether it be brought on by the shrinking of solid and stony masses during refrigeration, or by the condensation of gases, or any other imaginable cause, we have no reason to incline to the idea that the consequent geological changes are brought about so suddenly, as that large parts of continents are swallowed up at once in unfathomable subterranean abysses. If cavities be formed, they will be enlarged gradually, and as gradually filled. We read, indeed, accounts of engulphed

cities and areas of limited extent which have sunk down many yards at once; but we have as yet no authentic records of the sudden disappearance of mountains, or the submergence or emergence of great islands. On the other hand, the creeps in coal mines * demonstrate that gravitation begins to act as soon as a moderate quantity of matter is removed even at a great depth. The roof sinks in, or the floor of the mine rises, and the bent strata often assume as regularly a curved and crumpled arrangement as that observed on a grander scale in mountain-chains. The absence, indeed, of chaotic disorder, and the regularity of the plications in geological formations of high antiquity, although not unfrequently adduced to prove the unity and instantaneousness of the disturbing force, might with far greater propriety be brought forward as an argument in favour of the successive application of some irresistible but moderated force.

In conclusion, I may observe that the real point on which the whole controversy turns is the relative amount of work done by mechanical force in given quantities of time, past and present. Before we can determine the relative intensity of the force employed, we must have some fixed standard by which to measure the time expended in its development at two distinct periods. It is not the magnitude of the effects, however gigantic their proportions, which can inform us in the slightest degree whether the operation was sudden or gradual, insensible or paroxysmal. It must be shown that a slow process could never in any series of ages give rise to the same results.

The advocate of paroxysmal energy might assume an uniform and fixed rate of variation in times past and present for the animate world, that is to say, for the dying-out and coming-in of species, and then endeavour to prove that the changes of the inanimate world have not gone on in a corresponding ratio. But the adoption of such a standard of comparison would lead, I suspect, to a theory by no means favourable to the pristine intensity of natural causes. That the present state of the organic world is not stationary, can

* See Lyell's Elements of Geology, p. 50; and Student's Elements, p. 56.

be fairly inferred from the fact, that some species are known to have become extinct in the course even of the last three centuries, and that the exterminating causes always in activity, both on land and in the waters, are very numerous. But granting that a secular variation in the zoological and botanical worlds is going on, and is by no means wholly inappreciable to the naturalist, still it is certainly far less manifest than the revolution always in progress in the inorganic world. Indeed the quantity of sediment annually carried down by several of the most important rivers from the land to the sea, has already been so far measured as to enable the physicist by a simple arithmetical calculation to show approximately in how many years the minimum of change brought about by such a process would be capable of excavating the deepest valleys, and altering the height and volume of continental masses. Or, if we turn to the igneous forces, we find that every year some volcanic eruptions take place, and a rude estimate might be made of the number of cubic feet of lava and scoriæ poured or cast out of various craters. The amount of mud and sand deposited in deltas, and the advance of new land upon the sea, or the annual retreat of wasting sea-cliffs, are changes the amount of which might be roughly estimated. The extent of land raised above or depressed below the level of the sea might also be computed, and the change arising from such movements in a century might be conjectured. Suppose the average rise of the land in some parts of Scandinavia to be as much as two and a half feet in a hundred years, the present sea-coast might be uplifted 350 feet in fourteen thousand years; but we should have no reason to anticipate, from any zoological data hitherto acquired, that the molluscous fauna of the northern seas would in that lapse of years undergo any sensible amount of variation. We discover sea-beaches in Norway 700 feet high, in which the shells are identical with those now living, although their geographical distribution has somewhat altered, the fossil species constituting an assemblage which at present characterises the sea several degrees farther north. The rise of land in Scandinavia, however insensible to the inhabitants, has evidently been rapid when compared to the

rate of contemporaneous change in the testaceous fauna of the German Ocean. Were we to wait, therefore, till the mollusca shall have undergone as much alteration as they underwent between any two of the twelve larger groups from the Laurentian to the Pliocene (enumerated in the table at the end of this chapter), or even in the time intervening between the minor subdivisions of some of these groups, what stupendous revolutions in physical geography ought we not to expect, and how many mountain-chains might not be produced by the repetition of shocks of moderate violence, or by movements not even perceptible to man!

If we turn from the mollusca to the vegetable kingdom, and ask the botanist how many earthquakes and volcanic eruptions might be expected, and how much the relative level of land and sea might be altered, or how far the principal deltas will encroach upon the ocean, or the sea-cliffs recede from the present shores, before the species of European forest-trees will die out, he would reply that such alterations in the inanimate world might be multiplied indefinitely before he should have reason to anticipate, by reference to any known data, that the existing species of trees in our forests would disappear and give place to others. In a word, the movement of the inorganic world is obvious and palpable, and might be likened to the minute-hand of a clock, the progress of which can be seen and heard, whereas the fluctuations of the living creation are nearly invisible, and resemble the motion of the hour-hand of a timepiece. It is only by watching it attentively for some time, and comparing its relative position after an interval, that we can prove the reality of its motion.*

* See the Author's Anniversary Address, Quart. Journ. Geol. Soc. 1850, vol. vi. p. 46, from which some of the above passages are extracted.

ABRIDGED GENERAL TABLE OF FOSSILIFEROUS STRATA; SHOWING THEIR CHRONOLOGICAL SUCCESSION AND ORDER OF SUPERPOSITION.*

1. RECENT.		POST-TERTIARY.		NEOZOIC.
2. POST-PLIOCENE.		POST-TERTIARY.		NEOZOIC.
3. NEWER PLIOCENE.		PLIOCENE.	TERTIARY or CAINOZOIC.	NEOZOIC.
4. OLDER PLIOCENE.		PLIOCENE.	TERTIARY or CAINOZOIC.	NEOZOIC.
5. UPPER MIOCENE.		MIOCENE.	TERTIARY or CAINOZOIC.	NEOZOIC.
6. LOWER MIOCENE.		MIOCENE.	TERTIARY or CAINOZOIC.	NEOZOIC.
7. UPPER EOCENE.		EOCENE.	TERTIARY or CAINOZOIC.	NEOZOIC.
8. MIDDLE EOCENE.		EOCENE.	TERTIARY or CAINOZOIC.	NEOZOIC.
9. LOWER EOCENE.		EOCENE.	TERTIARY or CAINOZOIC.	NEOZOIC.
10. MAESTRICHT BEDS.		CRETACEOUS.		NEOZOIC.
11. WHITE CHALK.		CRETACEOUS.		NEOZOIC.
12. CHLORITIC SERIES.		CRETACEOUS.		NEOZOIC.
13. GAULT.		CRETACEOUS.	SECONDARY or MESOZOIC.	NEOZOIC.
14. NEOCOMIAN.		CRETACEOUS.	SECONDARY or MESOZOIC.	NEOZOIC.
15. WEALDEN.		CRETACEOUS.	SECONDARY or MESOZOIC.	NEOZOIC.
16. PURBECK BEDS.		JURASSIC.	SECONDARY or MESOZOIC.	NEOZOIC.
17. PORTLAND STONE.		JURASSIC.	SECONDARY or MESOZOIC.	NEOZOIC.
18. KIMMERIDGE CLAY.		JURASSIC.	SECONDARY or MESOZOIC.	NEOZOIC.
19. CORAL RAG.		JURASSIC.	SECONDARY or MESOZOIC.	NEOZOIC.
20. OXFORD CLAY.		JURASSIC.	SECONDARY or MESOZOIC.	NEOZOIC.
21. GREAT or BATH OOLITE.		JURASSIC.	SECONDARY or MESOZOIC.	
22. INFERIOR OOLITE.		JURASSIC.	SECONDARY or MESOZOIC.	
23. LIAS.		JURASSIC.	SECONDARY or MESOZOIC.	
24. UPPER TRIAS.		TRIASSIC.	SECONDARY or MESOZOIC.	
25. MIDDLE TRIAS.		TRIASSIC.	SECONDARY or MESOZOIC.	
26. LOWER TRIAS.		TRIASSIC.	SECONDARY or MESOZOIC.	
27. PERMIAN.		PERMIAN.	PRIMARY or PALÆOZOIC.	PALÆOZOIC.
28. COAL-MEASURES.		CARBONIFEROUS.	PRIMARY or PALÆOZOIC.	PALÆOZOIC.
29. CARBONIFEROUS LIMESTONE.		CARBONIFEROUS.	PRIMARY or PALÆOZOIC.	PALÆOZOIC.
30. UPPER	DEVONIAN.	DEVONIAN.	PRIMARY or PALÆOZOIC.	PALÆOZOIC.
31. MIDDLE	DEVONIAN.	DEVONIAN.	PRIMARY or PALÆOZOIC.	PALÆOZOIC.
32. LOWER	DEVONIAN.	DEVONIAN.	PRIMARY or PALÆOZOIC.	PALÆOZOIC.
33. UPPER	SILURIAN.	SILURIAN.	PRIMARY or PALÆOZOIC.	PALÆOZOIC.
34. LOWER	SILURIAN.	SILURIAN.	PRIMARY or PALÆOZOIC.	PALÆOZOIC.
35. UPPER	CAMBRIAN.	CAMBRIAN.	PRIMARY or PALÆOZOIC.	PALÆOZOIC.
36. LOWER	CAMBRIAN.	CAMBRIAN.	PRIMARY or PALÆOZOIC.	PALÆOZOIC.
37. UPPER	LAURENTIAN.	LAURENTIAN.	PRIMARY or PALÆOZOIC.	PALÆOZOIC.
38. LOWER	LAURENTIAN.	LAURENTIAN.	PRIMARY or PALÆOZOIC.	PALÆOZOIC.

* For a more detailed and extended list see Elements of Geology, 6th edit. p. 102; and Student's Elements, p. 109.

CHAPTER VIII.

DIFFERENCE IN TEXTURE OF THE OLDER AND NEWER ROCKS.

CONSOLIDATION OF FOSSILIFEROUS STRATA—SOME DEPOSITS ORIGINALLY SOLID —TRANSITION AND SLATY TEXTURE—CRYSTALLINE CHARACTER OF PLUTONIC AND METAMORPHIC ROCKS—THEORY OF THEIR ORIGIN—ESSENTIALLY SUBTERRANEAN—NO PROOFS THAT THEY WERE PRODUCED MORE ABUNDANTLY AT REMOTE PERIODS.

Consolidation of strata.—Another argument in favour of the dissimilarity of the causes operating at remote and recent eras has been derived by many geologists from the more compact, stony, and crystalline texture of the older as compared to the newer rocks.

This subject may be considered, first, in reference to the fossiliferous strata; and, secondly, in reference to those crystalline and stratified rocks which contain no organic remains, such as gneiss and mica-schist. There can be no doubt that the former of these classes, or the fossiliferous, are generally more compact and stony in proportion as they are more ancient. It is also certain that a great part of them were originally in a soft and incoherent state, and that they have been since consolidated. Thus we find occasionally that shingle and sand have been agglutinated firmly together by a ferruginous or siliceous cement, or that carbonate of lime in solution has been introduced, so as to bind together materials previously incoherent. Organic remains have sometimes suffered a singular transformation, as, for example, where shells, corals and wood are silicified, their calcareous or ligneous matter having been replaced by nearly pure silica. The constituents of some beds have probably set and become hard for the first time when they emerged form beneath the water.

But, on the other hand, we observe in certain formations now in progress, particularly in coral reefs, and in deposits from the waters of mineral springs, both calcareous and siliceous, that the texture of rocks may be stony from the first. This circumstance may account for exceptions to the general rule, not unfrequently met with, where solid strata are superimposed on others of a plastic and incoherent nature, as in the neighbourhood of Paris, where the tertiary formations, consisting often of compact limestone and siliceous grit, are more stony than underlying beds of the same series.

It will readily be understood, that the various solidifying causes, including those above enumerated, together with the pressure of incumbent rocks and the influence of subterranean heat, must all of them require time in order to exert their full power. If in the course of ages they modify the aspect and internal structure of stratified deposits, they will give rise to a general distinctness of character in the older as contrasted with the newer formations.

Transition texture.—In the original classification of Werner, the highly crystalline rocks, such as granite and gneiss, which contain no organic remains, were called primary, and the fossiliferous strata secondary, while to another class of an age intermediate between the primary and secondary he gave the name of transition. They were termed transition because they partook in some degree in their mineral composition of the nature of the most crystalline rocks, such as gneiss and mica-schist, while they resembled the fossiliferous series in containing occasionally organic remains, and also in exhibiting evident signs of a mechanical origin. It was at first imagined, that the rocks having this intermediate texture had been all deposited subsequently to the series called primary, and before all the more earthy and fossiliferous formations. But when the relative position and organic remains of these transition rocks were better understood, it was perceived that they did not all belong to one period. On the contrary, the same mineral characters were found in strata of very different ages, and some formations occurring

in the Alps, which several of the ablest scholars of Werner had determined to be transition, were ultimately ascertained, by means of their fossil contents and position, to be members of the Cretaceous, and even of the nummulitic or older tertiary period. These strata had, in fact, acquired the *transition* texture from the influence of causes which, since their deposition, had modified their internal arrangement.

Texture and origin of Plutonic and metamorphic rocks.— Among the most singular of the changes superinduced on rocks, we have occasionally to include the slaty texture, the divisional planes of which sometimes intersect the true planes of stratification, and even pass directly through imbedded fossils. If, then, the crystalline, the slaty, and other modes of arrangement, once deemed characteristic of certain periods in the history of the earth, have in reality been assumed by fossiliferous rocks of different ages and at different times, we are prepared to enquire whether the same may not be true of the most highly crystalline state, such as that of gneiss, mica-schist, and statuary marble. That the peculiar characteristics of such rocks are really due to a variety of modifying causes is now very generally admitted, and the differences of opinion among geologists which still prevail, relate chiefly to the manner in which the transformation has been brought about. According to the original Neptunian theory, all the crystalline formations were precipitated from a universal menstruum or chaotic fluid antecedently to the creation of animals and plants, the unstratified granite having been first thrown down so as to serve as a floor or foundation on which gneiss and other stratified rocks might repose. Afterwards, when the igneous origin of granite was no longer disputed, many conceived that a thermal ocean enveloped the globe, at a time when the first-formed crust of granite was cooling, but when it still retained much of its heat. The hot waters of this ocean held in solution the ingredients of gneiss, mica-schist, hornblende-schist, clay-slate, and marble, rocks which were precipitated, one after the other, in a crystalline form. No fossils could be enclosed in them, the high temperature of the fluid, and the quantity of mineral matter which

it held in solution, rendering it unfit for the support of organic beings.

It would be inconsistent with the plan of this work to enter here into a detailed account of what I have elsewhere termed the *metamorphic theory*; * but I may state that it is now demonstrable in some countries that fossiliferous formations, some of them older than the Cambrian strata of our table, p. 135, others of the age of the Silurian strata, as near Christiana in Norway, others belonging to the Oolitic period, as around Carrara in Italy, and some even of tertiary date, as in the Swiss Alps, have been converted into gneiss, mica-schist, or statuary marble. The transmutation has been effected by the influence of subterranean heat acting under great pressure, and aided by thermal water or steam and other gases permeating the porous rocks, and giving rise to various chemical decompositions and new combinations, the whole of which action has been termed 'plutonic,' as expressing in one word all the modifying causes brought into play at great depths, and under conditions never exemplified at the surface. † To this Plutonic action the fusion of granite itself in the bowels of the earth, as well as the development of the metamorphic texture in sedimentary strata, may be attributed; and in accordance with these views the age of each metamorphic formation may be said to be twofold, for we have first to consider the period when it originated, as an aqueous deposit, in the form of mud, sand, marl, or limestone; secondly, the date at which it acquired a crystalline texture. The same strata, therefore, may, according to this view, be very ancient in reference to the time of their deposition, and comparatively modern in regard to the period of their assuming the metamorphic character.

No proofs that these crystalline rocks were produced more abundantly at remote periods.—Several modern writers, without denying the truth of the Plutonic or metamorphic theory, still contend that the crystalline and non-fossiliferous formations, whether stratified or unstratified, such as gneiss and

* See Lyell's Elements, ch. xxxv.; and Student's Elements, p. 560.

† See Student's Elements: Remarks on hydrothermal action, p. 568.

granite, are essentially ancient as a class of rocks. They were generated, say they, most abundantly in a primeval state of the globe, since which time the quantity produced has been always on the decrease, until it became very inconsiderable in the Oolitic and Cretaceous periods, and quite evanescent before the commencement of the tertiary epoch.

Now the justness of these views depends almost entirely on the question whether granite, gneiss, and other rocks of the same order ever originated as such at the surface, or whether, according to the opinions above adopted, they are essentially subterranean in their origin, and therefore entitled to the appellation of *hypogene*. If they were formed superficially in their present state, and as copiously in the modern as in the more ancient periods, we ought to see a greater abundance of tertiary and secondary than of primary granite and gneiss; but if we adopt the theory of their subterranean origin, their rapid diminution in volume among the visible rocks in the earth's crust in proportion as we investigate the formations of newer date, is quite intelligible. If a melted mass of matter be now cooling very slowly at the depth of several miles beneath the crater of an active volcano, it must remain invisible until great revolutions in the earth's crust have been brought about. So also if stratified rocks are now by hydrothermal action, or under the influence of intensely heated steam and other gases, undergoing semi-fusion and reconstruction far underground, it will probably require the lapse of many periods before they will be forced up to the surface and exposed to view by denudation, even at a single point. To effect this purpose there may be need of as great a development of subterranean movement as that which in the Alps, Andes, and Himalayas has raised strata containing marine fossil shells and ammonites to the height of 8,000, 14,000, and 16,000 feet. By parity of reasoning we can hardly expect that any tertiary rocks of the hypogene class will have been brought within the reach of human observation, save at a few isolated points, seeing that the emergence of such rocks must always be so long posterior to the date of their origin; and,

as extensive denudation must also combine with upheaval before they can be displayed at the surface throughout wide areas, formations of this class cannot become generally visible until so much time has elapsed as to confer on them a high relative antiquity.

All geologists who reflect on subterranean movements now going on, and the eruptions of active volcanos, are convinced that great changes are now continually in progress in the interior of the earth's crust far out of sight. They must be conscious, therefore, that the inaccessibility of the regions in which these alterations are taking place compels them to remain in ignorance of a great part of the working of existing causes, so that they can only form vague conjectures in regard to the nature of the products which volcanic heat, aided by steam and various gases, may elaborate under great pressure.

When therefore they find in mountain-chains of high antiquity, that what was once the interior of the earth's crust has since been forced outwards by mechanical violence or exposed to view by denudation, they may expect to behold some of the nether formed rocks of remote eras, the modern representatives of which they cannot see. They may be prepared to find that these rocks will differ wholly from the fossiliferous strata deposited at the surface and from the lava and scoriæ thrown out by modern volcanos in the open air. They may recognise in granite, gneiss, mica-schist, hornblende schist, and other crystalline rocks, products of a nature and aspect distinct from those which they have observed in process of formation, and these they may therefore be ready to refer to the action of subterranean heat and gases under great pressure.

The contrast in the characters, both positive and negative, of such rocks with those which are known to be of superficial origin is a reason for referring them to operations which the geologist has had no opportunities of observing. The anomalous appearances are the result, not of an order of things which has passed away, but of a set of conditions removed by their very nature from the possibility of being

observed. They are not the monuments of the primeval period, bearing inscribed upon them in obsolete characters the words and phrases of a dead language; but they teach us that part of the living language of nature which we cannot learn by our daily intercourse with what passes on the habitable surface.

CHAPTER IX.

THEORY OF THE PROGRESSIVE DEVELOPMENT OF ORGANIC LIFE AT SUCCESSIVE GEOLOGICAL PERIODS.

THEORY OF THE PROGRESSIVE DEVELOPMENT OF ORGANIC LIFE—EVIDENCE IN ITS SUPPORT DERIVED FROM FOSSIL PLANTS—FOSSIL ANIMALS—MOLLUSCA—WHETHER THEY HAVE ADVANCED IN GRADE SINCE THE EARLIEST ROCKS WERE FORMED—HIGH ANTIQUITY OF CEPHALOPODA—SLIGHT INDICATIONS OF PROGRESS AFFORDED BY FOSSIL FISH—FOSSIL AMPHIBIA—TRUE REPTILES—TRANSITIONAL LINK BETWEEN REPTILES AND BIRDS—LAND ANIMALS OF REMOTE PERIODS WHY RARE—FOSSIL BIRDS—MAMMALIA—STONESFIELD MARSUPIALS—ABSENCE OF CETACEA IN SECONDARY ROCKS—SUCCESSIVE APPEARANCE OF THE GREAT SUB-CLASSES OF MAMMALIA OF ADVANCING GRADE IN CHRONOLOGICAL ORDER—MODERN ORIGIN OF MAN—INTRODUCTION OF MAN, TO WHAT EXTENT CHANGE IN THE SYSTEM.

In the last three chapters we considered whether the doctrine of the greater intensity of the aqueous and igneous forces in remote ages has any foundation in fact, and whether the peculiar crystalline texture of many of the older rocks favours the opinion that the former changes in the earth's crust, of which geology treats, were brought about by other than ordinary causes. We may now discuss the arguments derived from the organic creation in support of the notion that there is a want of analogy and continuity between the past and present course of events in the natural world. The objections on this head were formally stated in 1830, by the late Sir Humphry Davy. 'It is impossible,' he affirms, 'to defend the proposition, that the present order of things is the ancient and constant order of nature, only modified by existing laws: in those strata which are deepest, and which must, consequently, be supposed to be the earliest deposited, forms even of vegetable life are rare; shells and vegetable remains are found in the next order; the bones of fishes and oviparous reptiles exist in the following class; the remains

of birds, with those of the same genera mentioned before, in the next order; those of quadrupeds of extinct species in a still more recent class; and it is only in the loose and slightly consolidated strata of gravel and sand, and which are usually called diluvial formations, that the remains of animals such as now people the globe are found, with others belonging to extinct species. But, in none of these formations, whether called secondary, tertiary, or diluvial, have the remains of man, or any of his works, been discovered; and whoever dwells upon this subject must be convinced, that the present order of things, and the comparatively recent existence of man as the master of the globe, is as certain as the destruction of a former and a different order, and the extinction of a number of living forms which have no types in being. In the oldest secondary strata there are no remains of such animals as now belong to the surface; and in the rocks, which may be regarded as more recently deposited, these remains occur but rarely, and with abundance of extinct species;—there seems, as it were, a gradual approach to the present system of things, and a succession of destructions and creations preparatory to the existence of man.' *

In the above passages the author has done little more than reiterate the theory of progression which Lamarck had proposed about thirty years before in his Philosophy of Zoology. Another interval of more than forty years has again elapsed since Davy wrote, one marked by ever-increasing activity in palæontological research, yet the new facts brought to light have scarcely overturned any of the leading propositions above enumerated, although several of them have required to be considerably modified. Fossil remains of man and rude works of art have, it is true, been detected in the formations termed by Sir H. Davy diluvial, in which the bones of the mammoth and other extinct quadrupeds so frequently occur. But, although these discoveries have enabled us to trace back the memorials of our race one short step farther into the past, they have not shaken our belief in the extremely modern date of the human era, as compared to that of a

* Sir. H. Davy, Consolations in Travel: Dialogue III. 'The Unknown.'

series of antecedent epochs, each of them characterised by distinct species of animals and plants.* The dates of the successive appearance of certain classes, orders, and genera, those of higher organisation always characterising rocks newer in the series, have often been mis-stated,† and the detection of chronological errors has engendered doubts as to the soundness of the theory of progression. In these doubts I myself indulged freely in former editions of this work. But after numerous corrections have been made as to the date of the earliest signs of life on the globe, and the periods when more highly organised beings, whether animal or vegetable, first entered on the stage, the original theory may be defended in a form but slightly modified.

Fossil Plants.—To speak first of the vegetable creation—recent investigations have made it more and more clear that the oldest known flora was characterised by a great predominance of cryptogamous plants. In the Devonian flora of North America the lycopodiaceous genera, such as the Lepidodendra, were the most numerous, while the associated plants, such as Sigillariæ, ferns, and Coniferæ, although they are specifically distinct, agree generically with those of the carboniferous strata which come next in succession. It had been suggested that the absence, in the true coal, of the higher grade of flowering plants, (the dicotyledonous angiosperms of Brongniart,) which now constitute three-fourths of the vegetation of the globe, might be explained by supposing that the fossil species represent those only which grew in a particular class of stations, such as low swamps bordering the sea; and that more highly organised genera and species would have become known to us, had we been acquainted with the flora of the higher and mountainous regions. But although it is now universally admitted that the plants which form the bulk of the coal grew on the spots where we now find that fuel, yet there are many vegetable remains in the

* In my work on the Antiquity of Man, 1863, I have given, p. 295, a concise statement of the doctrine of progression as laid down by Prof. Sedgwick, the late Hugh Miller, M. Agassiz, Prof. Owen, and Profs. Bronn and Adolphe Brongniart, as applied both to the animal and vegetable worlds, which I need not repeat in the present chapter.

† See my Elements of Geology, p. 853.

associated sandstones, which must have been drifted from a distance or washed down by great rivers from higher grounds to the sea-coast. Nor can we point to a marsh in the delta of any existing river, where ferns and other Cryptogams together with Coniferæ flourish, to the exclusion of all the more highly organised plants.

Certain fruits and leaves of the coal-measures, formerly supposed to be those of palms, are now very generally referred to plants of less perfect structure, being variously classed by botanists as cycads, conifers, or lycopodiaceæ. There seems also ground for suspecting, in accordance with the suggestion of Dr. Dawson, that the flora of the Devonian rocks of North America was of a more upland character than that of the coal, and the mere fact of our having traced this ancient vegetation (the Devonian and Carboniferous), consisting of several hundred species, over so vast an area in space, in Europe and North America, and through such a lapse of ages, makes it probable that we have already obtained a correct notion of the leading features of the botany, both upland and lowland, of those palæozoic times. The almost entire want in this fossil flora, the first which geology has yet revealed to us, of plants of the most complex organisation is very striking, for not a single dicotyledonous angiosperm has yet been proved to exist in any primary formation, and only one undoubted monocotyledon,* although these two great divisions taken together form four-fifths of our living vegetation.

In regard to secondary or mesozoic times, all botanists agree that palms, with some other monocotyledons, were already in existence; but it seems doubtful whether any trace of a dicotyledonous angiosperm has yet been detected in rocks of the Triassic, Oolitic, or Lower Cretaceous (Neocomian), periods. Conifers, cycads, and ferns abounded, but the plants which now constitute the larger portion of our flora, and comprise all the native European trees except those of the fir tribe, seem not to have come into being, and must certainly have been extremely rare before the Upper Cretaceous

* *Pothocites Grantonii*, Paterson, from the coal shale cf Granton near Edinburgh. Edin. Bot. Soc. Trans. vol. i. plate 3, 1844. This plant, which is referred to the family Aroideæ, has the spike well preserved.

era. It is in strata of this latter age, at Aix-la-Chapelle, that we at length meet with an assemblage of fossil plants, in which the principal classes and orders of the living vegetable creation are fully represented. The variety and completeness of the fossil flora then attained continued to be conspicuous throughout a long succession of tertiary ages, in which the forms were perpetually changing, but always becoming more and more like, generically and specifically, to those now in being. On the whole there appears therefore to have been an advance in the fossil flora in the course of ages, although the cryptogamous plants of the Primary periods were some of them more perfect or of a higher grade than any of the same class now living. The Gymnogens (cycads and conifers) became more abundant, as also the Monocotyledons in the Secondary epochs, while in the Tertiary periods all the leading forms of the most complex dicotyledons now inhabiting the globe appear to have flourished.

Fossil Animals.—We may next turn to the animal kingdom, and consider the arguments derived from fossil vertebrata and invertebrata in favour of progressive development. Whenever these arguments are founded on negative evidence, we cannot be too cautious in our reasoning, and we must always bear in mind that it has been evidently no part of the plan of Nature to hand down to us a complete or systematic record of the former history of the animate world. We may have failed to discover a single shell, marine or fresh-water, or a single coral or bone in shale or sandstone, even in such a formation as that of the valley of the Connecticut, in which the footprints of bipeds and quadrupeds abound; but such failure may have arisen, not because the population of the land or sea was scanty at that era, but because in general the preservation of any relics of the animals or plants of former times in sedimentary formations is the exception to a general rule. It is only when the rocks are made up bodily of the remains of plants or animals, as in the case of beds of coal, chalk, or coral-limestone, that a representation of certain classes of the animal kingdom can be looked for as constituting an essential part of the formation. Time so enormous as that contemplated by the geologist may multiply exceptional cases till they seem to

constitute the rule, and so impose on the imagination as to lead us to infer the non-existence of creatures of which no monuments happen to remain. The late Edward Forbes remarked, that few geologists are aware how large a proportion of all known species of fossils are founded on single specimens, while a still greater number are founded on a few individuals discovered in one spot. This holds true not only in regard to animals and plants inhabiting the land, the lake, and the river, but even to a surprising number of the marine mollusca, articulata, and radiata. Our knowledge, therefore, of the living creation of any given period of the past may be said to depend in a great degree on what we commonly call chance, and the casual discovery of some new localities rich in peculiar fossils may modify, and, to a great extent, overthrow all our previous generalisations.

Mollusca.—Of all the invertebrate animals, the mollusca are the most important in geology, as, owing to the durable nature of their shells, they have been more generally preserved, in strata of every age, than the memorials of any other creatures. They are also peculiarly well fitted to throw light on the controverted question whether there has or has not been a gradual advance in the course of ages, from the humbler and more simple to the higher and more complex grades of structure. By a higher or more perfect organisation is meant one in which there are a greater number of organs specially devoted to particular functions. Thus in the lowest divisions, such as the Bryozoa and Brachiopoda, we find no separate organs of respiration, sight, or locomotion; whereas, in the lamellibranchiate bivalves, although they are without heads, we find a heart, gills, and foot, with several other organs, wanting in the inferior orders before alluded to. The Gasteropoda, again, have a head, mouth, lingual teeth, a special breathing apparatus, and nearly all of them organs of sight; while in the highest grade, the Cephalopoda, we meet with so many instruments appointed to perform distinct functions, such a concentration of the nervous system in what may be regarded as a brain, such acuteness of the senses, especially those of sight and touch, with such powers of locomotion, that we cannot refuse to assign to them a place superior to that

of all the other mollusca, and even to some few species of the vertebrata, although these last belong to a type which as a whole ranks so much higher in the scale.

We have now, therefore, to enquire whether the fossil representatives of the different divisions of the mollusca above enumerated, the Bryozoa, Brachiopoda, Lamellibranchiata, Gasteropoda, and Cephalopoda, made their appearance in succession in the ancient seas in the same order of time as they would stand in an ascending series in a zoological classification. In our endeavour to reply to this question it will be well to exclude from our survey the fossils of the lowest strata, or those older than the Lower Silurian (Nos. 35 and 36 of the Table, p. 135), with which we are so imperfectly acquainted that it is dangerous to derive from them any conclusions founded simply on negative evidence. Additions made from year to year may change the whole aspect of this primordial fauna of Barrande. Already indeed the notion of the extreme scarcity of organic remains and their inferiority of grade has to some extent had to be abandoned by the detection in it of an Orthoceras and of a rich fauna of trilobites, as well as other forms of life.

To begin then with the Lower Silurian (No. 34 of the same table), we find that it contains representatives of all the groups to which we have alluded, and the Cephalopoda alone have already furnished the conchologist with several hundred species and a long list of genera. Many of these chambered shells, especially the Orthocerata, were of large size, and they may possibly have swarmed the more in the ancient ocean because there were no fishes to compete with them. It has been remarked by the advocates of 'progressive evolution,' that all the cephalopods of this era are referable to the tetrabranchiata, or four-gilled form, a family which is not so highly organised as the dibranchiata (or two-gilled), to which the belemnites, so abundant in the Lias, Oolite, and Chalk, as well as the living cuttlefish, belong. Doubtless the absence of all genera of this highest order from the Silurian, Devonian, and Carboniferous formations may seem to imply that the testaceous fauna of the older rocks had not yet obtained so high a grade as it afterwards reached. But the

cogency of such reasoning is somewhat weakened by the fact, that several genera of Octopods now exist in our seas, which are without internal bones, like those possessed by the Sepia, or external shells, like those of the Nautilus. Such soft-bodied cephalopods, therefore, could not be expected to leave behind them any lasting memorials of their existence. It is only by assuming that there were no such genera in the palæozoic seas, that we can confidently infer a comparative inferiority of grade for the mollusca of that early period. It has been also remarked, in reference to the testaceous fauna of the primary strata, that while the lamellibranchiate bivalves are comparatively few in number, brachiopods of every variety of form are exceedingly abundant. It cannot be denied that the profusion of these last fixes on this earlier fauna a stamp of inferiority. But if we lay much stress on this argument, we find that it is somewhat counterbalanced by evidence bearing in an opposite direction, and equally derived from the proportional number of the representatives of different orders of mollusca. If the Brachiopoda outnumber the Lamellibranchiata in species, so, on the other hand, do the Cephalopods outnumber the Gasteropods, especially the highest division of these last, those which are siphonated, and which as zoophagous, marine animals seem to have been superseded by the Orthocerata, Nautilus, and their congeners. In this case, these last, being mollusca of a higher grade, discharged functions now performed to a great extent by Gasteropods, which are lower in the scale. On the whole, it cannot be said that the successive development, in the course of past ages, of higher and more complex structures, is by any means conspicuous in that grand branch of the animal kingdom which is most largely represented in a fossil state. The variety perhaps of types in the testacea is greater now than at any former period, but the rate of advance in organisation has been slow indeed, if the only step realised between Lower Silurian and modern times can be expressed by the passage from a tetrabranchiate to a dibranchiate cephalopod. According to such a rate of progress, we may well conceive that it might require a course of ages anterior to the Silurian epoch as great as that which has

since elapsed, in order to bring about a gradual evolution from a bryozoon to an orthoceras.

Fossil Fish.—The failure of the palæontologist to detect a single bone of any aquatic animal of the vertebrate class in rocks older than the Ludlow formation of Murchison, one of the uppermost divisions of the Silurian system, is a fact of no small weight in favour of progressive development, although as the oldest fish (Pteraspis), alluded to above, is by no means of the lowest grade, we may still expect to trace back the memorials of the great class of fishes to strata of higher antiquity. But when we consider how rich a molluscous fauna—to say nothing of the crustaceans, sea-urchins, stone-lilies, and corals—has been met with in Silurian rocks in almost all parts of the world, it seems impossible to account for our not having yet found any accompanying bones of fish, except by supposing that they were not yet in being, or that they only occupied a limited area. To verify the date of the first appearance of any new type of organisation is perhaps more than we can reasonably expect, as the first representatives of such types probably originate in one region only, from which they would spread very slowly over the globe.

Next to the Silurian comes the Old Red Sandstone or Devonian formation, which is so rich in fishes that the number of British species alone described by Agassiz, in 1844, amounted to sixty-five, and the number has since been raised to more than a hundred. Almost all of these belonged to the order of Ganoids, and some few only to that of the Placoids, of Agassiz; and it is remarkable that the vast majority of the fossil fish of the succeeding formations, from the Carboniferous to the Oolitic, consist in like manner of Ganoids, a family which, though so rich in genera in the olden times, is of quite exceptional occurrence at the present day, being confined to the North-American rivers, and those of Africa north of the line. In the chalk, and still more in the tertiary formations, we find the majority of the fish to belong to a great variety of genera of the class called *Teleostei* because their skeletons are perfectly ossified, which is very rarely the case with the Ganoids of the older rocks. The cartilaginous, persistent nature of the spinal column or

notochord, which is not divided into separate vertebræ, is regarded on the whole as a mark of a lower grade, as is also the form of the tail called heterocercal, which is almost universal in fish older than the chalk. Nearly all the living fish have equilobed tails, and the heterocercal or inequilobed form is looked upon by Owen as a retention of the embryonic character, or an instance of arrested development. But the affinity of the ancient Placoid and Ganoid fishes in the structure of their heart, brain, generative organs, and many other characters to living sharks, as well as to the African Polypterous and the bony pike, or Lepidosteus, of America, leads the anatomist to assign to them by no means a low place in the piscine class. In short, a retrospect of the history of this class in geological time 'imparts,' according to Professor Owen, 'an idea rather of mutation than of progression.' *

Reptiles.—No well-authenticated example of a reptile occurring in strata so old as the Devonian has yet been established,† and even in the succeeding Carboniferous formation, it was not till the year 1844 that some representatives of the lowest division of this class, the amphibia, which are regarded by some naturalists as intermediate between reptiles and fish, were discovered in the coal of Saarbruck. In 1852 Dr. Dawson and I discovered the osseous remains of a reptile in the Carboniferous strata of Nova Scotia, and in the same formation and country three other genera, all air-breathers, were found by Dr. Dawson, and described by him in his 'Air-breathers of the Coal.' Since that period several genera of the Labyrinthodont family, some containing species of large size, have been found in the carboniferous rocks of North America and Britain. So late as 1865, four or five new genera of this family determined by Professor Huxley have been added from the coal of Tipperary in Ireland. Some of these have well-ossified bony skeletons, although they belong to that sub-class which, like the frogs and newts, possessed gills at some period of their existence, and were also marked by other piscine characters. In rocks

* Owen's Palæontology, 2nd edit. p. 175.

† See Elements of Geology, 6th edition, p. 526 *note*.

of later age, from the Triassic to the Cretaceous inclusive, there is an extraordinary profusion of reptile life, to which I shall have occasion to allude again in the eleventh chapter, when treating of changes in climate. Two orders, the Dinosauria and Compsognatha, have been denominated Ornithoscelida, because, as Professor Huxley has especially pointed out, they supply in some important parts of their structure a transitional link between the reptiles and birds, more especially in the case of the *Compsognathus longipes*, a fossil form of the Solenhofen slate, a member of the Jurassic formation. The hind limbs in particular of these Ornithoscelida are much more similar to those of birds than they are to those of reptiles, and these bird-reptiles, or reptile-birds, were more or less completely bipedal.* No form of reptiles is so remarkable in the Secondary or Mesozoic formation as the winged reptiles called Pterodactyls, which sometimes attain a great size, one of them from the Kentish chalk measuring more than sixteen feet from tip to tip of its outstretched wings, and another in strata of the same age in America attaining even larger dimensions. Their batlike wings were not composed of feathers, as in birds, but appear to have consisted of an extended membrane which was supported, like that of bats, by the fourth digit, which was enormously elongated. They resemble birds in many of their osteological characters, among others in the presence of air-cavities in their bones, the prominent median crest of the broad breast-bone, and often in their horn-sheathed beaks. But they are, says Professor Huxley, rather a sort of reptilian bat than links between reptiles and birds.

Scarcity of air-breathers in primary rocks.—Our information respecting the fossils of the oldest rocks, especially those anterior to the Old Red Sandstone or Devonian formation, is almost exclusively derived from strata of marine origin. This we might have anticipated, if the ocean always occupied, as it does now, nearly five parts in seven of the earth's surface. After many geographical revolutions, after the sinking down of ancient continents and the upheaval of newer ones, it is natural that the strata of a very remote age

* Huxley, Pres. Add. Geol. Quart. Journ. 1870, vol. xxvi.

should coincide generally with the bed of the ancient ocean, rather than with the space which was occupied by land. Well therefore may we despair of gaining more than a superficial acquaintance with the terrestrial plants and air-breathing animals which once belonged to those small areas which represent spaces where palæozoic land of Silurian or Cambrian date may have happened to coincide with a portion of our present continents and islands. Even if they had never been submerged from the earliest period, they would have suffered such denudation by rain and rivers, either when the land was stationary, or when it was undergoing changes of level, that no parts of the old surface, or of its lacustrine and fluviatile deposits, would remain. Our best chance of hitting upon the spots where some monuments of such early times have escaped destruction, would arise from their submergence and the accumulation of marine strata upon them or upon the littoral deposits found in the immediate neighbourhood. Even then we could only obtain access to the buried strata, whether fresh-water or littoral, at those points where they had been exposed to view by the partial waste of the incumbent formations. The general absence therefore in Cambrian, Silurian, and Devonian rocks of all remains of land animals is not to be wondered at, and taken alone raises no very strong presumption against the existence, in palæozoic times, of air-breathers of the most highly organised class.

Up to the year 1865 only a few insects had been obtained even from the Carboniferous strata, the land plants of which are well known to us, and none from the Devonian. From this last formation several have now been brought to light in North America, chiefly of the order *Neuroptera*, found by Mr. Hartt, in rocks near St. John's, New Brunswick, and determined by Mr. Scudder, of Boston, U.S. Why then should we despair of finding in our future researches some air-breathers of a much higher order than insects, which may have peopled the forests of the Devonian era, in which some flowering plants of the monocotyledonous class, together with pines, tree-ferns, Sigillariæ, and Lepidodendra or gigantic Lycopodiaceæ, flourished. The first pulmoniferous mollusk,

a land shell, called *Pupa Vetusta*, of which hundreds of individuals have now been detected, was not discovered in the coal-measures until the year 1852, in Nova Scotia.

Birds.—In regard to birds, they are usually wanting, for reasons to be explained in the next volume, in deposits of all ages, even in the tertiary periods, where we know that birds as well as land quadrupeds abounded. But in the lithographic stone of Solenhofen, a division of the Upper Oolite, a skeleton of a bird almost entire, and retaining even some of its feathers, was found in 1862, and determined by Professor Owen to belong to the class Aves. It differs from all living birds in the structure of its fore limbs and still more of its tail, in which last there were no less than twenty vertebræ, each of them supporting a pair of plumes. In the tail of living birds the coalescence or anchylosed state of the terminal vertebræ is a constant character, the vertebræ being distinct and separate only in the embryo. The tail of the Archeopteryx therefore exhibits, as Professor Owen has pointed out, an earlier or more embryonic type persistent in the full-grown individual. Although no skeletons of the feathered tribe have been found in rocks older than the Oolite, yet the footmarks of a great variety of species of various sizes, some larger than the ostrich, others smaller than the plover, have been observed in rocks of higher antiquity in North America.* These bipeds have left the marks of their footsteps on strata of Triassic age in the valley of the Connecticut, and they are useful in warning us against speculating on the relative grade of ancient and modern representatives of this class, seeing that, although there were so many of these bipeds, we are so ignorant of their structure. Hitherto, even footprints of the class Aves have eluded our search in all formations older than the Trias, so that we may declare at present that the first appearance of fish, reptiles, and birds follows a chronological order in accordance with the position which the same classes would occupy when arranged zoologically by a naturalist in an ascending series: and we shall presently see that the lowest class of Mammalia

* See Hitchcock's Report on Geol. of Massachusetts, and Lyell's Travels in North America, chap. 12.

have not yet been traced back so far as the footprints of the earliest known birds.

Mammalia.—So late as the beginning of the present century it was a generally received dogma in geology that the

Fig. 3.

Thylacotherium Prevostii (*Valenciennes*). Amphitherium (*Owen*). Lower jaw, from the slate of Stonesfield, near Oxford.*

Mammalia had not been created before the Tertiary period, and the first announcement of the discovery in the Lower Oolite of Stonesfield, of the jaw of a small marsupial, recog-

Fig. 4.

Myrmecobius fasciatus (*Waterhouse*). Recent, from Swan River. Lower jaw of the natural size.†

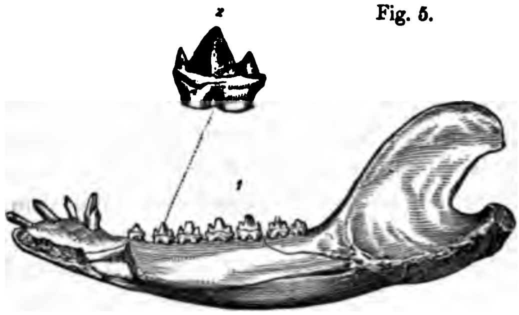
nised as such in 1818 by Cuvier, caused a sensation almost as great as would now be excited by our finding the bones of

* This figure (No. 3) is from a drawing by Professor C. Prevost, published Ann. des Sci. nat. avril 1825. The fossil is a lower jaw, adhering by its inner side to the slab of oolite, in which it is sunk. The form of the condyle, or posterior process of the jaw, is convex, agreeing with the mammiferous type, and is distinctly seen, an impression of it being left on the stone, although in this specimen the bone is wanting. The anterior part of the jaw has been partially broken away, so that the double fangs of the molar teeth are seen fixed in their sockets, the form of the fangs being characteristic of the mammalia. Ten molars are preserved, and the place of an eleventh is believed to be apparent. The enamel of some of the teeth is well preserved.

† A coloured figure of this small and elegant quadruped is given in the Trans. Zool. Soc. vol. ii. pl. 28. It is insectivorous, and was taken in a hollow tree, in a country abounding in ant-hills, ninety miles to the south-east of the mouth of Swan River in Australia. —It is the first living marsupial species known to have nine molar teeth in the lower jaw, and some of the teeth are widely separated from others, one of the peculiarities in the Thylacotherium of Stonesfield, which at first induced M. Blainville to refer that creature to the class of reptiles.

some quadrumanous animal in one of the Secondary rocks. Many naturalists, rather than allow their faith in the theory of progressive development to be so rudely shaken, cherished to the last a hope that it might ultimately turn out that the

Fig. 5.

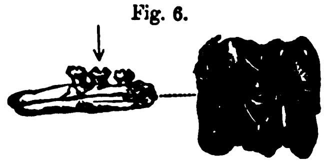


Natural size.

Phascolotherium Bucklandi (*Owen*). (*Syn.* Didelphis Bucklandi, *Brod.*) Lower jaw, from Stonesfield.*

1 The jaw magnified twice in length. 2 The second molar tooth magnified six times.

Fig. 6.



JAW OF STEREOGNATHUS, FROM STONESFIELD.

a. Portion of jaw with three molar teeth from Stonesfield oolite. Natural size. (*Owen's* Palæontology, p. 345.) *b.* Middle tooth of the three contained in the jaw *a.* (*Owen, Ibid.*, p. 346.)

British geologists had been mistaken in their opinion as to the age of the deposit in which this precious relic was entombed: while other eminent anatomists, M. Blainville among the number, called in question the mammalian character of

* This figure (No. 5) was taken from the original, formerly in Mr. Broderip's collection, and now in the British Museum. It consists of the right half of a lower jaw, of which the inner side is seen. The jaw contains seven molar teeth, one canine, and three incisors; but the end of the jaw is fractured, and traces of the alveolus of a fourth incisor are to be seen. With this addition, the number of teeth would agree exactly with those of a didelphis. The fossil is well preserved in a slab of oolitic structure containing shells of trigonia and other marine remains. See Broderip, Zool. Journ. vol. iii. p. 408. Owen, Proceedings Geol. Soc., November 1838.

the relic. But no less than nine other specimens of lower jaws of mammiferous quadrupeds have since been met with in the same slate of Stonesfield, so that, including the first found (fig. 3, p. 156), there are now four distinct species referable to three genera in this one member of the Lower Oolite.

After Cuvier had referred the specimen first met with to a marsupial, Professor Owen pointed out that the extinct genus to which it belonged had considerable affinity to an Australian mammifer, the *Myrmecobius* of Waterhouse, which has nine molar teeth in the lower jaw (see fig. 4).

The next representative of the same class found in the same slate was at once regarded as an opossum, with which it agrees nearly in osteological character, and precisely in the number of its teeth (fig. 5, p. 157). But the most remarkable of all the mammalia of which the remains have been found at Stonesfield, was that made known to the scientific world in 1854, under the name of *Stereognathus*.* The portion found consisted of part of a lower jaw containing three double-fanged teeth, indicating an animal small in size, but larger than any of the other quadrupeds as yet obtained from those rocks (see fig. 6). Although the teeth differed in structure from those of any recent or fossil animal yet known, they are admitted by anatomists to have more affinity to the higher or placental division of the mammalia than any of the species previously found at Stonesfield, or those yet procured from any rocks older than the Tertiary. It is conjectured by Professor Owen that it may have been a small, hoofed, herbivorous animal, or at least a mixed feeder, but he still regards this conclusion as doubtful; so far does *Stereognathus* depart from any known type whether living or extinct.

When the Stonesfield oolite had continued for nearly thirty years to be the only rock which had in any part of the world afforded an example of a fossil mammifer anterior in date to the Tertiary period, the tooth of another small marsupial mammifer, called Microlestes, was discovered in the Upper

* This generic name was given to it in 1854, by Mr. Charlesworth, who obtained it from the Rev. J. P. Dennis, in whose possession it had been for twenty years or more.

Trias of Stuttgardt in 1847.* Between that year and 1863 this rock and the Upper Trias of Somersetshire have yielded three species of the same genus, and a stratum probably of about the same age in North Carolina has supplied us with three jaws of a small insectivorous mammal, probably marsupial, called by the late Professor Emmons *Dromatherium sylvestre*. The only other mammalia as yet discovered in any other part of the globe in formations older than the Eocene are those of the uppermost Oolite or Purbeck strata in Dorsetshire, where about twenty-five species, referable to about eleven genera, have been met with between the years 1854 and 1871, all very small, most of them decidedly marsupial, and the rest, if not of the same sub-class, belonging to insectivora of low grade.†

It may, no doubt, be said that our acquaintance with the purely fresh-water strata of periods older than the Secondary is very defective, and that we ought therefore to expect that memorials of land animals in marine strata of Primary or Palæozoic date would be very exceptional. There are regions at present, in the Indian and Pacific Oceans, coextensive in area with Europe and North America, where we might dredge the bottom and draw up thousands of shells and corals, without obtaining one bone of a land quadruped. Suppose our mariners were to report, that, on sounding in the Indian Ocean near some coral reefs, and at some distance from the land, they drew up on hooks attached to their line portions of an ape, elephant, or leopard, should we not be sceptical as to the accuracy of their statements? and if we had no doubt of their veracity, might we not expect them to

* Elements, pp. 430–440.

† Only two species of Purbeck mammals discovered by Mr. Brodie and referred by Prof. Owen to his genus *Spalacotherium*, were known before the year 1856, when Mr. S. H. Beckles sent me a collection of fossils which I submitted to Dr. Falconer. From his interpretation of these remains, chiefly of lower jaws, I was enabled to announce in 1857, in the Supplement to my Manual or Elements of Geology, that no less than fourteen species of mammalia, referable to eight or nine genera, had then been obtained from a stratum a few inches thick of the Middle Purbeck, all within an area of 500 square yards. This number has now been increased to no less than twenty-five species, referable to eleven genera, and the whole of them admirably described and figured in a Monograph of the Palæontographical Society, 1870, by Prof. Owen. See also Elements, 6th ed. p. 379; and Student's Elements, 1871, p. 303.

be unskilled naturalists? or, if the fact were unquestioned, should we not be disposed to believe that some vessel had been wrecked on the spot?

The casualties must always be rare by which land quadrupeds are swept by rivers far out into the open sea, and still rarer the contingency of such a floating body not being devoured by sharks or other predaceous fish, such as were those of which we find the teeth preserved in some of the carboniferous strata; but if the carcase should escape, and should happen to sink where sediment was in the act of accumulating, and if the numerous causes of subsequent disintegration should not efface all traces of the body, included for countless ages in solid rock, it would be contrary to all calculation of chances that we should hit upon the exact spot, that mere point in the bed of an ancient ocean, where the precious relic was entombed. Can we expect for a moment, when we have only succeeded, amidst several thousand fragments of corals and shells, in finding a few bones of *aquatic* vertebrata, that we should meet with a single skeleton of an inhabitant of the land?

Clarence, in his dream, saw 'in the slimy bottom of the deep,'

> ——a thousand fearful wrecks;
> A thousand men, that fishes gnawed upon:
> Wedges of gold, great anchors, heaps of pearl.

Had he also beheld, amid 'the dead bones that lay scattered by,' the carcases of lions, deer, and the other wild tenants of the forest and the plain, the fiction would have been deemed unworthy of the genius of Shakespeare. So daring a disregard of probability and violation of analogy would have been condemned as unpardonable, even where the poet was painting those incongruous images which present themselves to a disturbed imagination during the visions of the night.

Absence of cetacea in secondary rocks.—But there is a negative fact of great significance which seems more than any other to render it highly improbable that we shall ever find air-breathers of the highest class in any of the primary strata, or in any of the older members of the secondary series.

This fact is the absence hitherto of all bones of cetacea among the numerous remains of fossil vertebrata entombed in rocks older than the Eocene. Cetacean bones are of rare occurrence in the Lower Tertiary formations of Europe, the only instance in Great Britain being a species of Monodon from the London clay, and the position even of this specimen is somewhat doubtful. But in the middle Eocene of America. as in Georgia and Alabama, the gigantic *Zeuglodon*, now admitted to be a true placental mammal, is by no means of uncommon occurrence.* The dimensions of the cetacea in general are such that they could hardly have failed to obtrude themselves on the notice of collectors had they been entombed in the mud and sand of Triassic, Liassic, or other secondary formations where the skeletons of huge reptiles are so conspicuous. The ichthyosaurs and other carnivorous saurians seem formerly to have played the part now assigned to the cetacea in the economy of nature; and if we assume this to have been the case, it seems probable that the placental mammalia, if they existed at all before the Tertiary period, were at least extremely scarce.

Successive appearance in chronological order of the great sub-classes of mammalia of higher and higher grade.—In a classification of mammalia, founded on the modification of their cerebral structure, Professor Owen has assigned the lowest place to a sub-class called Lyencephala, which comprises two orders, the Marsupialia and the Monotremata. In this last are included the *Echidna* (or duckbilled Platypus) of Australia and the *Ornithorhynchus* of the same continent. No members of this lowest division of the mammalia have yet been found fossil, but we ought to look for their remains in the Carboniferous and other primary rocks, should air-breathers higher than the class of reptiles ever be discovered in them, assuming that a thorough knowledge of the succession in time of the fossil vertebrata would bear out fully the theory of progressive development from the simplest to the most complex types. We should then have

* The supposed cetaceans of the cretaceous rocks, which I formerly cited on the authority of Dr. Leidy, have lately been ascertained by him to be of Miocene date.—Leidy, Reptiles of the Chalk.

monotremata in the Primary, marsupials in the Secondary, and placentals in the Tertiary strata, assuming for the present that the class to which *Stereognathus* belongs is still undetermined.

In the history of the Tertiary and Post-tertiary series, it may be said that there is in the mammalia a still farther evolution from the less to the more perfect structures. For the earliest known species of the placental sub-class does not belong to the Quadrumanous order, the most ancient representative of that sub-class being the *Arctocyon primævus*, which has been met with in France in Eocene strata older than the Plastic clay or Woolwich beds. Of later date than this, M. Rütimeyer has recognised, in a member of the Middle Eocene group of the Swiss Jura, the jawbone of a monkey allied in some points to the Mycetes or howling monkey of America and in others to the Lemurs. If this determination be confirmed when more of the skeleton has been discovered, the *Cœnopithecus lemuroides* would constitute the oldest known example of a fossil quadrumanous animal.* The next step occurs in the Upper Miocene or Falunian deposits of Europe, in which several examples of the monkey tribe have been met with, and among them some of the *anthropomorphous* apes. One of them, the *Dryopithecus*, allied to the Gibbon, discovered in the South of France, rivalled man in stature. If in the Pliocene strata, which followed next in the order of time, no quadrumana have been detected, we may attribute their absence to the diminished warmth of the Pliocene climate, which began to resemble that now enjoyed in the south of Europe, instead of being, like that of the Upper Miocene, sub-tropical. For evidence of the gradual development of the monkeys, apes, and orangs, and of the first appearance of man, the progressionist will naturally look to those countries which escaped the rigours of the Glacial Period, whereas our most careful investigations have hitherto been confined to the

* The fossil monkey named Macacus Eocenus by Owen, found in 1840, at Kyson, near Ipswich in Suffolk, in a stratum older than the London clay, and which I formerly cited as quadrumanous on the authority of Prof. Owen, was pronounced by the same anatomist in 1862 to be a pachyderm, more ample data for its correct determination having been obtained.

temperate latitudes of the northern hemisphere, whether in the Old or New World. However slender therefore may be the foundation of facts on which such grand generalisations are built, and however anxious we may be not to place too much reliance on the soundness of our inferences, we may yet say that the direction in which the facts point are decidedly towards the theory of progression. It may no doubt be said that the entire area from which the Secondary or Mesozoic species of mammalia, thirty-three in number, have been obtained is confined to a very limited part of the globe, even when we include the site of the Dromatherium of North Carolina, between three and four thousand miles distant from Stuttgardt. But on the other hand we must recollect that the time throughout which this fauna has been traced is of vast duration, extending from the Rhœtic or Upper Triassic beds to those which form the Purbeck or last stage of the great Oolitic era. In Australia at present, out of more than two hundred living species of mammalia above three-fourths are marsupial, and the remaining species are confined to the orders of bats and rodents which are small in size and belong to the Lissencephala or lowest sub-class of placental mammalia, when classified according to cerebral development. In the ancient strata of Mesozoic age so far as yet known we also find a predominance of undoubted marsupials, associated with some species which may perhaps be placental, but which, if so, are diminutive in size, and belonging to orders of a low grade in that class. During the long period throughout which this mammalian fauna was persistent, there were abundance of terrestrial and aquatic reptiles, and the species both of the vertebrate and invertebrate classes were frequently changing, so that the absence of a single cetacean, or other representative of the Gyrencephalous orders can hardly be regarded as wholly accidental, or attributed entirely to our limited acquaintance with the air-breathers of the period in question. We may at least affirm that, in the present state of our knowledge, a comparison of this mammalian fauna with that of the Tertiary era which succeeded it next in chronological order, points to

a law of progressive development from the more simple to the more complex.

We have then been fairly led by palæontological researches to the conclusion that the invertebrate animals flourished before the vertebrata, and that in the latter class fish, reptiles, birds, and mammalia made their appearance in a chronological order analogous to that in which they would be arranged zoologically according to an advancing scale of perfection in their organisation. In regard to the mammalia themselves, they have been divided by Professor Owen, in the classification already alluded to (p. 161), into four sub-classes by reference to modifications of their brain. In the two lowest, called Lyencephala and Lissencephala, are included the marsupials and insectivora, and these have been met with fossil in the secondary rocks. Next above them in grade are the Gyrencephala, in which Cetaceans, Proboscidians, Ruminants, Carnivora, and Quadrumana are classed, all of which are found fossil in tertiary strata. Among these the Quadrumana rank highest, and the Anthropomorphous family takes the lead in organisation and instinct among the Quadrumana, coming also last in the order of time. To crown the whole, the series ends with the fourth great sub-class, the Archencephala, of which man is the sole representative, and of which the fossil remains have not yet been detected in deposits older than the post-tertiary.

Antecedently to investigation, we might reasonably have anticipated that the vestiges of man would have been traced back at least as far as those Pliocene strata in which nearly all the testacea and a certain number of the mammalia are of existing species, for of all the mammalia the human species is the most cosmopolite, and perhaps more capable than any other of surviving considerable vicissitudes in climate, and in the physical geography of the globe.

No inhabitant of the land exposes himself to so many dangers on the waters as man, whether in a savage or a civilised state; and there is no animal, therefore, whose skeleton is so liable to become imbedded in lacustrine or submarine deposits: nor can it be said that his remains are more perishable than those of other animals; for in ancient

fields of battle, as Cuvier has observed, the bones of men have suffered as little decomposition as those of horses which were buried in the same grave. But even if the more solid parts of our species had disappeared, the impression of their form might have remained engraven on the rocks, as have the traces of the tenderest leaves of plants, and the soft integuments of many animals. Works of art, moreover, composed of the most indestructible materials, would have outlasted almost all the organic contents of sedimentary rocks. Edifices, and even entire cities, have, within the times of history, been buried under volcanic ejections, submerged beneath the sea, or engulphed by earthquakes; and had these catastrophes been repeated throughout an indefinite lapse of ages, the high antiquity of man would have been inscribed in far more legible characters on the framework of the globe than are the forms of the ancient vegetation which once covered the islands of the northern ocean, or of those gigantic reptiles which at still later periods peopled the seas and rivers of the northern hemisphere.

Introduction of Man, to what extent a change of the system.—I shall defer to the next volume the discussion of a theoretical question of surpassing interest with which the palæontologist has been busily engaged ever since the time of Lamarck, namely, whether it is conceivable that each fossil fauna and flora brought to light by the geologist may have been connected, by way of descent or generation, with that which immediately preceded it, our record being so defective that nearly all the intermediate links by which a transition was effected from genus to genus, or from species to species, have in most cases left behind them no vestiges of their former existence. In support of this opinion, it has been argued that the earliest remains of man imply a rude state of the arts and an entire ignorance of the use of metals. On the other hand, little or no progress has been made in discovering fossil remains which indicate any inferiority in the cerebral development of the men who were contemporary with the mammoth, and were the fabricators of the earliest known stone weapons. It may fairly be argued that the superiority of man depends, not on those faculties and

attributes which he shares in common with the lower animals, but on his reason, by which he is distinguished from them. When it is said that the human race is of far higher dignity than were any pre-existing beings on the earth, it is the intellectual and moral attributes of our race, rather than the physical, which are considered; and it is by no means clear that the organisation of man is such as would confer a decided pre-eminence upon him, if, in place of his reasoning powers, he was merely provided with such instincts as are possessed by the lower animals. Without entering at present into the discussion of this and other cognate questions, we may endeavour to answer an objection which has been made to the doctrine of the past uniformity of nature.

Is not the interference of the human species, it is asked, such a deviation from the antecedent course of physical events that the knowledge of such a fact tends to destroy all our confidence in the uniformity of the order of nature, both in regard to time past and future? If such an innovation could take place after the earth had been exclusively inhabited for thousands of ages by inferior animals, why should not other changes as extraordinary and unprecedented happen from time to time? If one new cause was permitted to supervene, differing in kind and energy from any before in operation, why may not others have come into action at different epochs? Or what security have we that they may not arise hereafter? And if such be the case, how can the experience of one period, even though we are acquainted with all the possible effects of the then existing causes, be a standard to which we can refer all natural phenomena of other periods?

Now these objections would be unanswerable, if adduced against one who was contending for the absolute uniformity throughout all time of the succession of sublunary events—if, for example, he was disposed to indulge in the philosophical reveries of some Egyptian and Greek sects, who represented all the changes both of the moral and material world as repeated at distant intervals, so as to follow each other in their former connection of place and time. For they compared the course of events on our globe to astronomical cycles; and not only did they consider all sublunary affairs to be under the

influence of the celestial bodies, but they taught that on the earth, as well as in the heavens, the same identical phenomena recurred again and again in a perpetual vicissitude. The same individual men were doomed to be re-born, and to perform the same actions as before: the same arts were to be invented, and the same cities built and destroyed. The Argonautic expedition was destined to sail again with the same heroes, and Achilles with his Myrmidons to renew the combat before the walls of Troy.

> Alter erit tum Tiphys, et altera quæ vehat Argo
> Dilectos heroas; erunt etiam altera bella,
> Atque iterum ad Trojam magnus mittetur Achilles.*

The geologist, however, may condemn these tenets as absurd, without running into the opposite extreme, and denying that the order of nature has, from the earliest periods, been uniform in the same sense in which we believe it to be uniform at present, and expect it to remain so in future. We have no reason to suppose, that when man first became master of a small part of the globe, a greater change took place in its physical condition than is now experienced when districts, never before inhabited, become successively occupied by new settlers. When a powerful European colony lands on the shores of Australia, and introduces at once those arts which it has required many centuries to mature; when it imports a multitude of plants and large animals from the opposite extremity of the earth, and begins rapidly to extirpate many of the indigenous species, a mightier revolution is effected in a brief period than the first entrance of a savage horde, or their continued occupation of the country for many centuries, can possibly be imagined to have produced. If there be no impropriety in assuming that the system is uniform when disturbances so unprecedented occur in certain localities, we can with much greater confidence apply the same language to those primeval ages when the aggregate number and power of the human race, or the rate of their advancement in civilisation, must be supposed to have been far inferior. In

* Virgil, Eclog. iv. For an account of these doctrines, see Dugald Stewart's Elements of the Philosophy of the Human Mind, vol. ii. chap. ii. sect. 4; and Prichard's Egypt. Mythol. p. 177.

reasoning on the state of the globe before the existence of man, we must be guided by the same rules of induction as when we speculate on the state of America in the interval that elapsed between the introduction of man into Asia, the supposed cradle of our race, and the arrival of the first adventurers on the shores of the New World. In that interval, we imagine the state of things to have gone on according to the order now observed in regions unoccupied by man. Even now, the waters of lakes, seas, and the great ocean, which teem with life, may be said to have no immediate relation to the human race—to be portions of the terrestrial system of which man has never taken, nor ever can take, possession; so that the greater part of the inhabited surface of the planet may still remain almost as insensible to our presence as before any isle or continent was appointed to be our residence.

If the barren soil around Sydney had at once become fertile upon the landing of our first settlers; if, like the happy isles whereof the poets have given us such glowing descriptions, those sandy tracts had begun to yield spontaneously an annual supply of grain, we might then, indeed, have fancied alterations still more remarkable in the economy of nature to have attended the first coming of our species into the planet. Or if, when a volcanic island like Ischia was, for the first time, brought under cultivation by the enterprise and industry of a Greek colony, the internal fire had become dormant, and the earthquake had remitted its destructive violence, there would then have been some ground for speculating on the debilitation of the subterranean forces, when the earth was first placed under the dominion of man. But after a long interval of rest, the volcano bursts forth again with renewed energy, annihilates one half of the inhabitants, and compels the remainder to emigrate. The course of nature remains evidently unchanged; and, in like manner, we may suppose the general condition of the globe, immediately before and after the period when our species first began to exist, to have been the same, with the exception only of man's presence.

The modifications in the system of which man is the

instrument do not, perhaps, constitute so great a deviation from previous analogy as we usually imagine; we often, for example, form an exaggerated estimate of the extent of our power in extirpating some of the inferior animals, and causing others to multiply; a power which is circumscribed within certain limits, and which is by no means exclusively exerted by our species.* The growth of human population cannot take place without diminishing the numbers, or causing the entire destruction, of many animals. The larger beasts of prey in particular give way before us; but other quadrupeds of smaller size, and innumerable birds, insects, and plants, which are inimical to our interests, increase in spite of us, some attacking our food, others our raiment and persons, and others interfering with our agricultural and horticultural labours. We behold the rich harvest which we have raised by the sweat of our brow, devoured by myriads of insects, and are often as incapable of arresting their depredations, as of staying the shock of an earthquake, or the course of a stream of lava.

A great philosopher has observed, that we can command Nature only by obeying her laws; and this principle is true even in regard to the astonishing changes which are superinduced in the qualities of certain animals and plants by domestication and garden culture. I shall point out in the next volume that we can only effect such surprising alterations by assisting the development of certain instincts, or by availing ourselves of that mysterious law of their organisation, by which individual peculiarities are transmissible from one generation to another.†

It is probable, from these and many other considerations, that as we enlarge our knowledge of the system, we shall become more and more convinced, that the alterations caused by the interference of man deviate far less from the analogy of those effected by other animals than is usually supposed.‡ We are often misled, when we institute such comparisons, by our knowledge of the wide distinction between the instincts of animals and the reasoning power of man; and we are apt

* See Ch. XLII.

† See Ch. XXXVI.

‡ See Ch. XXXVIII., XXXIX., XL., XLII.

hastily to infer, that the effects of a rational and irrational species, considered merely *as physical agents*, will differ almost as much as the faculties by which their actions are directed.

It is not, however, meant by the foregoing observations to convey the idea, that a real departure from the antecedent course of physical events cannot be traced in the introduction of man. If that latitude of action which enables the brutes to accommodate themselves in some measure to accidental circumstances could be imagined to have been at any former period so great, that the operations of instinct were as much diversified as are those of human reason, it might, perhaps, be contended, that the agency of man did not constitute an essential deviation from the previously established order of things. It might then have been said that the advent of man upon the earth was an era in the moral, not in the physical world—that our study and contemplation of the earth, and the laws which govern its animate productions, ought no more to be considered in the light of a disturbance or deviation from the system, than the discovery of the satellites of Jupiter should be regarded as a physical event affecting those heavenly bodies. Their influence in advancing the progress of science among men, and in aiding navigation and commerce, was accompanied by no reciprocal action of the human mind upon the economy of nature in those distant planets; and so the earth might be conceived to have become, at a certain period, a place of moral discipline and intellectual improvement to man, without the slightest derangement of a previously existing order of change in its animate and inanimate productions.

The distinctness, however, of the human from all other species, considered merely as an efficient cause in the physical world, is real; for we stand in a relation to contemporary species of animals and plants widely different from that which irrational animals can ever be supposed to have held to each other. We modify their instincts, relative numbers, and geographical distribution, in a manner superior in degree, and in some respects very different in kind, from that in which any other species can affect the rest. Besides, the progressive movement of each successive generation of men

causes the human species to differ more from itself in power and intelligence at two distant periods, than any one species of the higher order of animals differs from another. The establishment, therefore, by geological evidence, of the intervention of such a peculiar and unprecedented agency, long after other parts of the animate and inanimate world existed, affords ground for concluding that the experience during thousands of ages of all the events which may happen on this globe, would not enable a philosopher to speculate with confidence concerning future contingencies. But his reliance need not be shaken in the unvarying constancy of the laws of nature, or in his power of reasoning from the present to the past in regard to the changes of the terrestrial system, whether in the organic or inorganic world, provided that he does not deny, in the organic world at least, the possibility of a law of evolution and progress.

CHAPTER X.

FURTHER CONSIDERATION OF THE AGREEMENT OF THE ANCIENT AND MODERN CAUSES OF CHANGE—VICISSITUDES IN CLIMATE.

ARGUMENTS DERIVED FROM FORMER DIFFERENCES IN CLIMATE—THE REALITY OF SUCH FORMER DIFFERENCES CONSIDERED—CLIMATE OF THE AGES OF BRONZE AND OF STONE—FOSSIL QUADRUPEDS AND SHELLS OF THE DRIFT—TEMPERATURE IMPLIED BY THE REMAINS OF THE MAMMOTH AND OTHER EXTINCT QUADRUPEDS—CARCASES OF THE ELEPHANT AND RHINOCEROS PRESERVED IN THE FROZEN MUD OF SIBERIA—IMPORTANT BEARING OF THE CONDITION OF THESE FOSSIL REMAINS ON THE THEORY OF CLIMATE—VARIATION IN THE TEMPERATURE OF POST-GLACIAL TIMES—ORGANIC AND INORGANIC PROOFS OF GREAT COLD IN THE GLACIAL EPOCH—INTER-GLACIAL PERIODS OF DÜRNTEN AND CROMER—BRITISH PLIOCENE STRATA, SHOWING TRANSITION FROM WARMER TO COLDER CLIMATE—THE SIGNS OF WARM TEMPERATURE AFFORDED BY ITALIAN PLIOCENE STRATA—WARM CLIMATE OF CENTRAL EUROPE IN UPPER MIOCENE TIMES—REPTILES AND QUADRUMANA—FOSSILS OF THE SIWÂLIK HILLS—UPPER MIOCENE STRATA OF WEST INDIES—WARM CLIMATE IMPLIED BY LOWER MIOCENE FAUNA AND FLORA—MIOCENE FOREST TREES IN HIGH ARCTIC LATITUDES—HIGH TEMPERATURE OF THE EOCENE PERIOD—SUPPOSED SIGNS OF ICE-ACTION IMPLIED BY ERRATIC BLOCKS OF UPPER MIOCENE AND MIDDLE EOCENE CONGLOMERATES.

Climate of the Northern Hemisphere formerly different.—ANOTHER objection to the theory which endeavours to explain all geological changes by reference to causes now in action is founded on the former prevalence of climates hotter than those now experienced in corresponding latitudes. We have seen (p. 41) that Hooke, about the year 1688, grounded his belief in the reality of the higher temperature of the waters of the ancient sea on the occurrence of fossil turtles and ammonites in the Portland oolite. In later times the shells and corals of the other fossiliferous strata, some older and some newer than this Secondary or Mesozoic rock, were appealed to as confirmatory of the same conclusions, whilst the botanist referred to the character of the fossil flora of the ancient carboniferous rocks as favourable to the same doctrine.

All indications of a high temperature recognised in the older formations were the more readily accepted because they seemed to lend support to the hypothesis of the primeval igneous fusion of the planet, the mass of which, while it radiated heat into the surrounding atmosphere and ocean, had gradually cooled, and had been constantly acquiring a thicker crust.

Since I first attempted, in the year 1830, to account for vicissitudes of climate by reference to changes in the physical geography of the globe,* our knowledge of the subject has greatly increased, and the problem to be solved has assumed a somewhat new aspect. More extended observations have shown that in times past the climate of the extra-tropical regions has by no means been always hotter than now, but, on the contrary, there has been at least one period, and one of very modern date geologically speaking, when the temperature of those regions was much lower than at present. It will be desirable, therefore, before entering into a discussion of the probable causes of the changes of temperature which have been experienced since the earliest of the fossiliferous rocks were formed, to lay before the reader a brief account of the evidence by which the reality of such changes has been established.

At first sight it may seem to be the simplest way of dealing with this subject to begin with a description of the proofs deduced from organic remains of the state of things in very remote times, and then to pass on to successive variations in climate manifested by the fauna and flora of later epochs. But such a method is impracticable, for not only are all the animals and plants found fossil in the oldest rocks specifically distinct from those now living, but a large part of the genera and not a few of the orders to which they belong have for ages ceased to exist. Consequently, when we attempt to make such a comparison with the view of determining the difference of the climates which prevailed at two distant periods, we find it almost impossible to apply the rules derived from the study of the present state of the animate world to another which differed from it so widely. The thread of

* Principles of Geology, 1st edition. 1830.

induction seems broken, and we become convinced that in order to make good our ground, and to reason securely from the known to the unknown, we must first ascertain the relation which the present organic creation bears to that of the period immediately antecedent, when the species of mollusca or those fossils with which we have most to deal were nearly all identical, and then carry back our retrospect step by step to formations of older date. In adopting this course we have the advantage of comparing, in the first instance, the species now in being, of which the habits and physiological characters are known, with the animal and vegetable remains entombed in the Tertiary formations, in which, as we have seen in the last chapter, all the classes of animals and plants are represented in proportions very analogous to those now prevailing. By this means we escape the danger of one source of error, namely, that of ascribing the predominance of certain genera or families to a difference in climate while in reality this predominance may have depended not on temperature but on the absence of competing tribes of higher grade, which, according to the law of progressive development, had not yet made their appearance on the earth.

Climate of the Ages of Bronze and of Stone.—In pursuance, then, of this method of enquiry, we may consider, in the first place, the climate of Europe in times immediately anterior to the historical. We there find no indications of any marked divergence from the present condition of things, whether in the memorials of the age of bronze or in those of the Neolithic age,* which preceded it, namely, that to which the Danish kitchen-middens and many of the Swiss lake dwellings belonged.

It is evident that the plants and animals which co-existed with man in those ages were identical with species now living in the same countries, with the exception of a few known to have been locally extirpated in historical times.

The next antecedent era of which we have acquired any information is that designated by the late M. Lartet 'the

* Sir John Lubbock, in his 'Prehistoric Times,' p. 3, has proposed the term 'Neolithic' for this more modern age of stone, calling the older stone period, that in which man was contemporary with many extinct mammalia, 'Palæolithic.'

Reindeer period,' when that northern animal, together with several others fitted for a cold climate, extended its range to the foot of the Pyrenees. The mammoth and cave-lion, quadrupeds more characteristic of an anterior period, have been found sparingly in this fauna, and another extinct quadruped, the Irish elk or gigantic deer.* The weapons then in use by man show a rude state of the arts, and complete ignorance of the use of metals. Passing over this intermediate period, which is as yet but vaguely and imperfectly defined, we come to the older stone age, or 'Palæolithic Period,' comprising the ancient river-gravels of Amiens and Abbeville in France, and of Salisbury and Bedford in England, and the superficial deposits of many other parts of Europe. Here, for the first time in our retrospect, we encounter the bones of a large number of extinct species of the genera elephant, rhinoceros, bear, tiger, and hyæna, associated with the remains of living animals and of man. The human relics consist almost entirely in North-western Europe of unpolished flint implements of a type different from those of the later or Neolithic era, implying a less advanced state of civilisation. The gravels containing such works of art and bones of extinct animals belong to a time when some of the minor features of the physical geography were different from those now characterising the same part of Europe, a discordance which does not hold true of the more modern or Neolithic times. The valleys of the more ancient of the two periods had not acquired their present width, depth, and outline. The bones of man and rude works of art occur also in caves associated with the remains of mammalia similar to those of the palæolithic gravels above mentioned. The enormous volume of alluvial matter formed in the channels of the old rivers, the contorted stratification of some parts of such alluvium, and the large size of many of the transported stones which it contains, imply a climate which generated much snow and ice in winter, and a mean annual temperature lower than that now found in the same parts of Europe.† The fossil shells also imbedded

* See Mr. Boyd Dawkins' list of mammalia of the Dordogne Caves, Quart. Journ. of Sci., July 1866, p. 343.

† For contortions of the drift, see Antiquity of Man, by the Author, p. 138.

in the same deposits are all of species now living, and characteristic, with a few exceptions to be mentioned in the sequel, of Central and Northern Europe. The general absence of the bones of reptiles, even of those of small dimensions, is very significant, as indicating a former state of the atmosphere and of the waters uncongenial to that class of vertebrata.

Climate of the mammoth and its associates.—Geologists, when they first examined the fossils of the drift, approached the subject with the fullest conviction on their minds that the climate of the globe in the olden times was warmer than it is now. This opinion they had legitimately derived from the study of the Tertiary and Secondary rocks, and when they encountered the bones of the elephant, rhinoceros, hippopotamus, lion, tiger, and hyæna plentifully entombed in the old river-gravels above mentioned, and in the contemporaneous mud and breccia of caverns, they concluded, without hesitation, that as all the genera alluded to are now characteristic of warmer latitudes, their presence was in perfect harmony with the received doctrine. The fact that the numerous land and fresh-water shells accompanying the same fossils were almost without exception identical with those now inhabiting the same country, ought doubtless to have served as a warning against the belief in a hotter climate; but the well-known forms of many large and conspicuous mammalia made a greater impression on their minds than the comparatively diminutive mollusca, with which few were familiar. The late Dr. Fleming, however, before the notion had gained ground that a glacial epoch had intervened between tertiary and historical times, called in question, in 1829, the opinion that the bones of the elephant and rhinoceros, and other associated pachyderms and beasts of prey, implied a tropical climate. A near resemblance, he observed, in form and osteological structure is not always followed in the existing mammiferous fauna by a similarity of geographical distribution; and we must therefore be on our guard against deciding too confidently, from mere analogy of anatomical structure, respecting the habits and physiological peculiarities of *species* now no more. 'The zebra,' he marked, 'delights to roam over the tropical plains; while the horse can maintain its existence

throughout an Iceland winter. The buffalo, like the zebra, prefers a high temperature, and cannot thrive even where the common ox prospers. The musk-ox, on the other hand, though nearly resembling the buffalo, prefers the stinted herbage of the arctic regions, and is able, by its periodical migrations, to outlive a northern winter. The jackal (*Canis aureus*) inhabits Africa, the warmer parts of Asia, and Greece; while the isatis, or arctic fox (*Canis lagopus*), resides in the arctic regions. The African hare and the polar hare have their geographical distribution expressed in their trivial names;' * and different species of bears thrive in tropical, temperate, and arctic latitudes.

Other writers soon followed up the same line of argument, and Mr. Hodgson, among others, in his account of the mammalia of Nepal, stated that the tiger was sometimes found at the very edge of perpetual snow in the Himalaya.† Pennant had previously mentioned, that it had been seen among the snows of Mount Ararat in Armenia, and later authorities have placed it beyond all doubt that a species of tiger identical with that of Bengal is common in the neighbourhood of Lake Aral, near Sussac, in the forty-fifth degree of North latitude. Humboldt remarks, that the part of Southern Asia now inhabited by this Indian species of tiger is separated from the Himalaya by two great chains of mountains, each covered with perpetual snow,—the chain of Kuenlun, lat. 35° N., and that of Mouztagh, lat. 42°,—so that it is impossible that these animals should merely have made excursions from India, so as to have penetrated in summer to the forty-eighth and fifty-third degrees of North latitude. They must remain all the winter north of the Mouztagh, or Celestial Mountains. The last tiger killed, in 1828, on the Lena, in lat. 52½°, was in a climate colder than that of St. Petersburg and Stockholm.‡

A species of panther (*Felis irbis*), covered with long hair, has been discovered in Siberia, evidently inhabiting, like the

* Fleming, Ed. New Phil. Journ., No. xii. p. 282. 1829.

† Journ. of Asiat. Soc., vol. i. p. 240.

‡ Humboldt, Fragmens de Géologie, &c., tome ii. p. 388. Ehrenberg. Ann. des Sci. nat., tome xxi. pp. 387, 390.

tiger, a region north of the Celestial Mountains, which are in lat. 42°.*

In regard to the climate of the living elephant, the Rev. Robert Everest observes, that the greatest elevation at which it is found in a wild state is in the north-west Himalaya, at a place called Nahun, about 4,000 feet above the level of the sea, and in the 31st degree of N. lat., where the mean yearly temperature may be about 64° Fahrenheit, and the difference between winter and summer very great, equal to about 36° F., the month of January averaging 45°, and June, the hottest month, 91° F.†

Von Schrenck, writing in 1858, announced that in Amoorland, part of North-Eastern Asia, then recently annexed to the Russian Empire, no less than 34 out of 58 living quadrupeds are identical with European species. Among those which are not European, some are arctic, others of tropical forms; in illustration of which, he states that the Bengal tiger, ranging sometimes northwards as far as lat. 42°, subsists chiefly on the flesh of the reindeer, while on the other hand, the small tailless hare or pika occasionally wanders from its polar haunts to parts of Amoorland as far south as 48°.‡ In America, the jaguar has been seen wandering from Mexico as far north as Kentucky, lat. 37° N.§, and in the opposite direction as far as 42° S. in South America,—a latitude which corresponds to that of the Pyrenees in the northern hemisphere.|| The range of the puma is still wider, for it roams from the equator to the Straits of Magellan, being often seen at Port Famine, in lat. 53° 38′ S. When the Cape of Good Hope was first colonised, the two-horned African rhinoceros was found in lat. 34° 29′ S., accompanied by the elephant, hippopotamus, and hyæna. Here the migration of all these species towards the south was arrested by the ocean; but if the African continent had been prolonged still farther, and the land had been of moderate elevation, it is highly

* Ehrenberg, Ann. des Sci. nat., tome xxi. pp. 387, 390.

† Everest on Climate of Foss. Eleph., Journ. of Asiat. Soc., No. 25, p. 21.

‡ Nat. Hist. Rev., vol. i. p. 12, 1861. Antiquity of Man, p. 158.

§ Rafinesque, Atlantic Journ., p. 18.

|| Darwin's Journal of Travels in South America, &c., 1832 to 1836, in Voyage of H.M.S. Beagle, p. 159.

probable that they might have extended their range to a greater distance from the tropics.

Now, if the Indian tiger can range in our own times to the southern borders of Siberia, or skirt the snows of the Himalaya, and if the puma can reach the fifty-third degree of latitude in South America, we may easily understand how large species of the same *genera* may once have inhabited Northern Europe. The mammoth (*E. primigenius*), already alluded to, as occurring fossil in England, was decidedly different from the two living species of elephants, one of which is limited to Asia, south of the 31° of N. lat., the other to Africa, where it extends, as before stated, as far south as the Cape of Good Hope. The bones of the fossil species are very widely spread over Europe and North America; but are nowhere in such profusion as in Siberia, particularly near the shores of the Frozen Ocean.

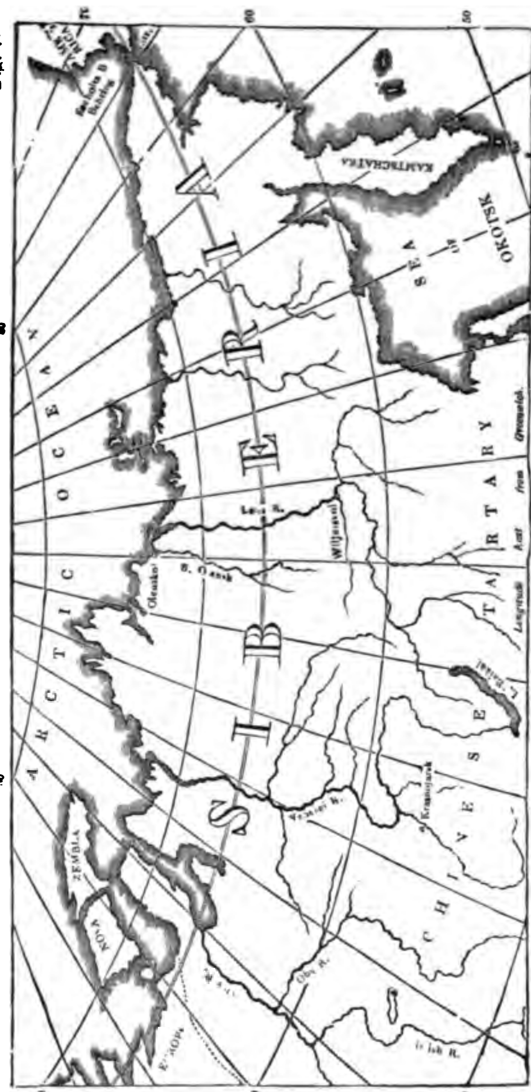
But if we are thence to conclude that this animal preferred a northern climate, it will naturally be asked, By what food was it sustained, and why does it not still survive near the Arctic circle? * Pallas and other writers describe the bones of the mammoth as occurring in a very fresh state throughout all the Lowland of Siberia, stretching in a direction west and east, from the borders of Europe to the extreme point nearest America, from south to north, from lat. 60° and from the base of the mountains of Central Asia to the shores of the Arctic Sea. (See map, fig. 7, p. 180.) Within this space, scarcely inferior in area to the whole of Europe, fossil ivory has been collected almost everywhere, on the banks of the Irtish, Obi, Yenesei, Lena, and other rivers. The elephantine remains do not occur in the marshes, but where the banks of the rivers present lofty precipices of sand and clay; from which circumstance Pallas very justly inferred that, if sections could be obtained, similar bones might be found in all the elevated lands intervening

* The speculations which follow, on the ancient physical geography of Siberia, and its former fitness as a residence for the mammoth, were first given in my 4th edition, June 1835. Sir R. Murchison and his companions, MM. de Verneuil and Keyserling, in their great work on the Geology of Russia, 1845 (vol. i. p. 497), have, in citing this chapter, declared that their investigations have led them to similar conclusions.

between the great rivers. Strahlenberg, indeed, had stated, before the time of Pallas, that wherever any of the great

Fig. 7.

MAP OF SIBERIA.



Map showing the course of the Siberian rivers from south to north, from temperate to arctic regions, in the country where the fossil bones of the mammoth abound.

rivers overflowed and cut out fresh channels during floods, more fossil remains of the same kind were invariably disclosed.

As to the position of the bones, Pallas found them in some places imbedded together with marine remains; in others, simply with fossil wood, or lignite, such as, he says, might have been derived from carbonised peat. On the banks of the Yenesei, below the city of Krasnojarsk, in lat. 56°, he observed grinders and bones of elephants, in strata of yellow and red loam, alternating with coarse sand and gravel, in which was also much petrified wood of the willow and other trees. Neither here nor in the neighbouring country were there any marine shells, but merely layers of black coal.* But grinders of the mammoth were collected much farther down the same river, near the sea, in lat. 70°, associated with *marine* remains.† Many other places in Siberia are cited by Pallas, where sea shells and fishes' teeth accompany the bones of the mammoth, rhinoceros, and Siberian buffalo, or bison (*Bos priscus*).

Carcasses of elephant and rhinoceros preserved in frozen mud,—But it is not on the Obi nor the Yenesei, but on the Lena, farther to the east, where, in the same parallels of latitude, the cold is far more intense, that fossil remains were first found in the most wonderful state of preservation In 1772, Pallas obtained from Wiljuiskoi, in lat. 64°, from the banks of the Wiljui, a tributary of the Lena, the carcass of a rhinoceros (*R. tichorhinus*), taken from the sand in which it must have remained congealed for ages, the soil of that region being always frozen to within a slight depth of the surface. This carcass, which was compared to a natural mummy, emitted an odour like putrid flesh, part of the skin being still covered with short crisp wool and with black and grey hairs. In allusion to the quantity of hair on the foot and head conveyed to St. Petersburg, Pallas asked whether this animal might not have inhabited a cold region of Middle Asia, its clothing being so much warmer than that of the African rhinoceros.‡

Professor Brandt, of St. Petersburg, in a letter to Baron Alex. Von Humboldt, dated 1846, adds the following particulars respecting this wonderful fossil relic :—' I have been

* Pallas, Reise im Russ. Reiche, pp. 409, 410.

† Nov. Com. Pétrop., vol. xvii. p. 584.

‡ Ibid. p. 591.

so fortunate as to extract from cavities in the molar teeth of the Wiljui rhinoceros a small quantity of its half-chewed food, among which fragments of pine-leaves, one-half of the seed of a polygonaceous plant, and very minute portions of wood with porous cells (or small fragments of coniferous wood), were still recognisable. It was also remarkable, on a close investigation of the head, that the blood-vessels discovered in the interior of the mass appeared filled, even to the capillary vessels, with a brown mass (coagulated blood), which in many places still showed the red colour of blood.'*

Thirty years after the discovery of the rhinoceros by Pallas, the entire carcass of a mammoth was obtained in 1803, by Mr. Adams, much farther to the north. It fell from a mass of ice, in which it had been encased, on the banks of the Lena, in lat. 70°; and so perfectly had the soft parts of the carcass been preserved, that the flesh, as it lay, was devoured by wolves and bears. This skeleton is still in the museum of St. Petersburg, the head retaining its integument and many of the ligaments entire. The skin of the animal was covered, first, with black bristles, thicker than horsehair, from twelve to sixteen inches in length; secondly, with hair of a reddish-brown colour, about four inches long; and thirdly, with wool of the same colour as the hair, about an inch in length. Of the fur, upwards of thirty pounds' weight were gathered from the wet sandbank. The individual was nine feet high and sixteen feet long, without reckoning the large curved tusks: a size rarely surpassed by the largest living male elephants.†

It is evident, then, that the mammoth, instead of being naked, like the living Indian and African elephants, was enveloped in a thick shaggy covering of fur, probably as impenetrable to rain and cold as that of the musk-ox.‡ The species may, as Cuvier observed,§ have been fitted by nature to withstand the vicissitudes of a northern climate; and it is certain that, from the moment when the carcasses, both of

* Quart. Journ. Geol. Soc. Lond., vol. iv. p. 10, Memoirs.

† Journal du Nord, St. Petersburg, 1807.

‡ Fleming, Ed. New Phil. Journ., No. xii. p. 285, 1829.

§ Ossements fossils, 4th ed., 1836.

the rhinoceros and elephant, above described, were buried in Siberia, in latitudes 64° and 70° N., the soil must have remained frozen, and the atmosphere as cold as at this day. The discoveries made in 1843 by Mr. Middendorf, a distinguished Russian naturalist, and which he communicated to me in September 1846, afford more precise information as to the climate of the Siberian Lowlands, at the period when the extinct quadrupeds were entombed. One elephant was found on the Tas, between the Obi and Yenesei, near the Arctic circle, about lat. 66° 30′ N., with some parts of the flesh in so perfect a state that the ball of the eye is now preserved in the Museum at Moscow. Another carcass, together with a young individual of the same species, was met with in the same year, 1843, in lat. 75° 15′ N., near the river Taimyr, with the flesh decayed. It was imbedded in strata of clay and sand, with erratic blocks, at about fifteen feet above the level of the sea. In the same deposit Mr. Middendorf observed the trunk of a larch-tree (*Pinus larix*), the same wood as that now carried down in abundance by the Taimyr to the Arctic Sea. There were also associated marine shells of *living northern* species, and which are moreover characteristic of the drift or *glacial* deposits of Scotland and other parts of Europe. Among these, *Nucula pygmæa*, *Tellina calcarea*, *Mya truncata*, and *Saxicava rugosa* were conspicuous.

So fresh is the ivory throughout Northern Russia, that, according to Tilesius, thousands of fossil tusks have been collected and used in turning; yet others are still procured and sold in great plenty. He declares his belief that the bones still left in Northern Russia must greatly exceed in number those of all the elephants now living on the globe.

Remains of the mammoth have been collected from the cliffs of frozen mud and ice on the east side of Behring's Straits, in Eschscholtz Bay, in Russian America, lat. 66° N. As the cliffs waste away by the thawing of the ice, tusks and bones fall out, and a strong odour of animal matter is exhaled from the mud.*

In 1866, in the flat country near the mouths of the Yenesei, between lat. 70° and 75° N., many skeletons of mammoths

* See Dr. Buckland's description of these bones, Appen. to Beechy's Voyage.

were found retaining the skin and hair. The heads of most of them are said to have been turned towards the south. So late as 1869–70, an exploring expedition was made by Herr von Maydell, under the direction of the Academy of St. Petersburg, to the river Indigiska, to examine some remains said to have been discovered there. We learn from M. Brandt* that the travellers found the skin and hair as well as the bones of the *Elephas primigenius* at two points on the river, about thirty miles distant from each other, and sixty-six miles from the Arctic Sea. In one of the localities a perfect skull also was dug out. The preservation of these and other individuals before mentioned in ice or frozen mud is a fact which has a most important bearing on all speculations concerning the climate of the Arctic regions, both at the time when these animals existed, and throughout the whole period which has since elapsed. There may have been oscillations of temperature, accompanying changes in the geography of the globe, or partly due to distinct phases of the precession of the equinoxes, or to various states of the ellipticity of the earth's orbit since the era in question; but one thing is clear, that the ice or congealed mud in which the bodies of such quadrupeds were enveloped has never once been melted since the day when they perished, so as to allow the free percolation of water through the matrix, for had this been the case, the soft parts of the animals could not have remained undecomposed.

Rome is the most southern limit to which the fossil bones of the mammoth have as yet been traced in Europe. Some were detected in 1858 in Monte Sacro, in the environs of Rome, where they were recognised by M. Lartet among the mammalian remains obtained by Prof. Ponzi from the volcanic gravel of that locality. Other specimens, as I learn from M. de Verneuil, have since been found in ancient alluvium on the banks of the Tiber, at Ponte Molle, associated with flint implements of contemporaneous date.

We are not obliged, says Dr. Falconer, to suppose that this ancient elephant, which in Europe extended its range

* Bull. de l'Acad. Imp. des Sciences St. Petersburg, vol. xv. p. 347.

from the Tiber to the Lena, and in North America from Eschscholtz Bay to the Gulf of Mexico, was enveloped in every latitude with a thick covering of fur. 'The fine silky fleece with which the domestic goat is clothed on the plains of Tibet, where the winter, at a height of 16,000 feet above the sea, is most severe, disappears entirely from the same animal in the valley of Cashmere.'*

Dr. Fleming, long before the discovery above alluded to by Brandt, of fossil pine-leaves in the molar of a Siberian rhinoceros, had hinted, that 'the kind of food which the existing species of elephant prefers will not enable us to determine, or even to offer a probable conjecture, concerning that of the extinct species. No one,' he said, 'acquainted with the gramineous character of the food of our fallow-deer, stag, or roe, would have assigned a lichen to the reindeer.'

Travellers mention that, even now, when the climate of Eastern Asia is so much colder than the same parallels of latitude farther west, there are woods not only of fir, but of birch, poplar, and alder, on the banks of the Lena, as far north as latitude 69° 5′.†

Professor Owen observes, that the teeth of the mammoth differ from those of the living elephants, whether Asiatic or African, having a larger proportion of dense enamel, which may have enabled it to subsist on the coarser ligneous tissues of trees and shrubs. In short, he is of opinion, that the structure of its teeth, as well as the nature of its epidermis and coverings, may have made it 'a meet companion for the reindeer.'

It has been suggested, that as, in our own times, the northern animals migrate, so the Siberian elephant and rhinoceros may have wandered towards the north in summer. The musk-oxen annually desert their winter quarters in the south, and cross the sea upon the ice, to graze for four months, from May to September, on the rich pasturage of Melville Island, in lat. 75°. The mammoth may in like manner have made excursions, during the warmth of a northern summer, from the central or temperate parts of Asia to the

* Falconer, American Fossil Elephant, Nat. Hist. Rev., vol. iii. 1863.

† History of British Fossil Mammalia, 1844, p. 261 *et seq.*

75th parallel of latitude, even though the continuous land may not have extended so far.

If such were the case, the preservation of their bones, or even occasionally of their entire carcasses, in ice or frozen soil, may be accounted for, without resorting to speculations concerning sudden revolutions in the former state and climate of the earth's surface. We seem entitled to assume, that, in the time of the extinct elephant and rhinoceros, the Lowland of Siberia stretched less far towards the north than now; for we have seen (p. 181) that the strata of this Lowland, in which the fossil bones lie buried, were originally deposited beneath the sea; and we know, from the facts brought to light in Wrangel's Voyage, in the years 1821, 1822, and 1823, that a slow upheaval of the land along the borders of the Icy Sea is now constantly taking place, similar to that experienced in part of Sweden. In the same manner, then, as additions have been made to the shores of the Gulf of Bothnia, not only by the influx of sediment brought down by rivers, but also by the elevation and consequent drying up of the bed of the sea, so a like combination of causes may, in modern times, have been extending the low tract of land where marine shells of arctic species now existing and fossil bones occur in Siberia. In fact, the observations of Sir R. Murchison and other travellers have shown that such an extension has actually taken place. Such a change in the physical geography of that region, implying a constant augmentation in the quantity of arctic land, would, according to principles to be explained in the twelfth chapter, tend to increase the severity of the winters, and, by limiting the supply of food, finally contribute to the extermination of the mammoth and its contemporaries.

On referring to the map (p. 180), the reader will see how all the great rivers of Siberia flow at present from south to north, from temperate to arctic regions, and they are all liable, like the Mackenzie, in North America, to remarkable floods, in consequence of flowing in this direction. For they are filled with running water in their upper or southern course when still frozen over for several hundred miles near their mouths, where they remain blocked up by ice for six

months in every year. The descending waters, therefore, finding no open channel, rush over the ice, often changing their direction, and sweeping along forests and prodigious quantities of soil and gravel mixed with ice. Now the rivers of Siberia are among the largest in the world, the Yenesei having a course of 2,500, the Lena of 2,000 miles; so that we may easily conceive that the bodies of animals which fall into their waters may be transported to vast distances towards the Arctic Sea, and, before arriving there, may be stranded upon and often frozen into thick ice. Afterwards, when the ice breaks up, they may be floated still farther towards the ocean, until at length they become buried in fluviatile and submarine deposits near the mouths of rivers.

Humboldt remarks, that near the mouths of the Lena a considerable thickness of frozen soil may be found at all seasons at the depth of a few feet; so that if a carcass be once imbedded in mud and ice in such a region and in such a climate, its putrefaction may be arrested for indefinite ages.* According to Prof. Von Baer of St. Petersburg, the ground is now frozen permanently to the depth of 400 feet at the town of Yakutzk, on the western bank of the Lena, in lat. 62° N., 600 miles distant from the Polar Sea. Mr. Hedenstrom tells us that, throughout a wide area in Siberia, the boundary cliffs of the lakes and rivers consist of alternate layers of earthy materials and ice, in horizontal stratification;† and Mr. Middendorf told me in 1846, that, in his tour there three years before, he had bored in Siberia to the depth of seventy feet, and, after passing through much frozen soil mixed with ice, had come down upon a solid mass of pure transparent ice, the thickness of which, after penetrating two or three yards, they did not ascertain.

The late Sir John Richardson informed me, that in the northern parts of America, comprising regions now inhabited by many herbivorous quadrupeds, the drift snow is often converted into permanent masses of ice. This snow is commonly blown over the edges of steep cliffs, so as to form an inclined

* Humboldt, Fragmens asiatiques, tom. ii. p. 393.

† Reboul, Géol. de la Période quaternaire, who cites Observ. sur la Sibérie, Bibl. Univ., juillet 1832.

talus hundreds of feet high; and when a thaw commences, torrents rush from the land, and throw down from the top of the cliff alluvial soil and gravel. This new soil soon becomes covered with vegetation, and protects the foundation of snow from the rays of the sun. Water occasionally penetrates into the crevices and pores of the snow; but, as soon as it freezes, it serves the more effectively to consolidate the mass into compact ice. It may sometimes happen that cattle grazing in a valley at the base of such cliffs, on the borders of a river, may be overwhelmed by drift snow, and at length enclosed in solid ice, and then transported towards the polar regions. Or a herd of mammoths, returning from their summer pastures in the north, may have been surprised, while crossing a stream, by the sudden congelation of the waters. The missionary Huc relates, in his Travels in Tibet in 1846, that, after many of his party had been frozen to death, the survivors pitched their tents on the banks of the Mouroui-Ousson (which lower down becomes the famous Blue River), and saw from their encampment 'some black shapeless objects ranged in file across the stream. As they advanced nearer, no change either in form or distinctness was apparent; nor was it till they were quite close, that they recognised in them a troop of the wild oxen, called Yak by the Tibetans.* There were more than fifty of them encrusted in the ice. No doubt they had tried to swim across at the moment of congelation, and had been unable to disengage themselves. Their beautiful heads, surmounted by huge horns, were still above the surface, but their bodies were held fast in the ice, which was so transparent that the position of the imprudent beasts was easily distinguishable; they looked as if still swimming, but the eagles and ravens had pecked out their eyes.'†

Considering all the facts above enumerated, it seems reasonable to imagine that a large region in Central Asia, including, perhaps, the southern half of Siberia, enjoyed, at no very remote period in the earth's history, a climate

* Conjectured to be the wild stock of Bos grunniens.

† Recollections of a Journey through Tartary, Tibet, and China (ch. xv. p. 234), by M. Huc. Longman, 1852.

sufficiently mild to afford food for numerous herds of elephants and rhinoceroses, *of species distinct from those now living*. It has often been taken for granted that herbivorous animals, of large size, require a very luxuriant vegetation for their support; but this opinion is, according to Mr. Darwin, completely erroneous:—'It has been derived,' he says, 'from our acquaintance with India and the Indian islands, where the mind has been accustomed to associate troops of elephants with noble forests and impenetrable jungles. But the southern parts of Africa, from the tropic of Capricorn to the Cape of Good Hope, although sterile and desert, are remarkable for the number and great bulk of their indigenous quadrupeds. We there meet with an elephant, five species of rhinoceros, a hippopotamus, a giraffe, the *Bos Caffer*, the elan, two zebras, the quagga, two gnus, and several antelopes. Nor must we suppose that, while the species are numerous, the individuals of each kind are few. Dr. Andrew Smith saw, in one day's march, in lat. 24° S., without wandering to any great distance on either side, about 150 rhinoceroses, with several herds of giraffes, and his party had killed, on the previous night, eight hippopotamuses. Yet the country which they inhabited was thinly covered with grass and bushes about four feet high, and still more thinly with mimosa-trees, so that the waggons of the travellers were not prevented from proceeding in a nearly direct line.'*

In order to explain how so many animals can find support in this region, it is suggested that the underwood, of which their food chiefly consists, may contain much nutriment in a small bulk, and also that the vegetation has a rapid growth; for no sooner is a part consumed, than its place, says Dr. Smith, is supplied by a fresh stock. Nevertheless, after making every allowance for this successive production and consumption, it is clear, from the facts above cited, that the quantity of food required by the larger herbivora is much less than we have usually imagined. Mr. Darwin conceives that the amount of vegetation supported at any one time by Great Britain may exceed, in a tenfold ratio, the quantity existing

* Darwin, Journal of Travels in S. America, &c., 1832–1836, in Voyage of H.M.S. Beagle, p. 98. 2nd ed., London 1845, p. 86.

on an equal area in the interior parts of Southern Africa. It is remarked, moreover, in illustration of the small connection discoverable between abundance of food and the magnitude of indigenous mammalia, that while in the desert part of Southern Africa there are so many huge animals, there is not, in Brazil, where the splendour and exuberance of the vegetation are unrivalled, a single wild quadruped of the largest size.

It would doubtless be impossible for herds of mammoths and rhinoceroses to subsist, at present, throughout the year, even in the southern part of Siberia, covered as it is with snow during winter; but there is no difficulty in supposing a vegetation capable of nourishing these great quadrupeds to have once flourished between the latitudes 40° and 65° N.

Climate of European Drift and Cave Deposits.—We may now ask, with what European deposits does the frozen mud of Siberia containing the remains of the mammoth in so fresh a state correspond geologically? Their superficial distribution, and the species of mammalia, as well as the fact that the shells which Middendorf and others observed in them are of living species, seem to connect them chronologically with that palæolithic drift in which flint implements have been detected in England, France, and Italy. The temperature which prevailed in the valleys of the Thames, Somme, and Seine at the era in question, was, according to Mr. Prestwich, 20° Fahrenheit colder than now, or such as would now belong to a country from 10° to 15° of latitude more to the north.* This estimate is founded on a careful analysis of the land and fresh-water shells which accompany the remains of the mammoth and its associates in the palæolithic alluvium. If we confine our attention to those terrestrial shells which are most commonly buried in the same gravel and sand as the *Elephas primigenius* and *Rhinoceros tichorhinus*, we find them to amount to no less than 48 species in the valley of the Thames and its neighbourhood. All but two of these still survive in Britain; these two, *Helix incarnata* and *Helix ruderata*, still inhabit the continent of Europe, and have a great range from north to south. The

* Prestwich, Phil. Trans., 1864, part 2, p. 89.

associated fresh-water shells, more than twenty in number, are also British species; but as they occur, with two or three exceptions, as far north as Finland, their presence is not opposed to the hypothesis of a cold climate, especially as the *Limnææ* are capable of being frozen up, and then reviving again when the river-ice melts. At Fisherton, near Salisbury, one of the rude flint implements of the earliest stone age was found in drift containing the mammoth and Siberian rhinoceros, together with the Greenland lemming and a *Spermophilus*, another northern form of rodent allied to the marmot, besides the tiger, hyena, horse, and other extinct and living species; the whole assemblage being confirmatory of the opinion, that the men of the early stone period had often to contend with a climate more severe than that now prevailing in the same parts of Europe.* The late Edward Forbes compared the condition of Britain and the neighbouring parts of the continent, during the period next preceding the historical, to the 'barren grounds' of Boreal America, including the Canadas, Labrador, Rupert's Land, and the countries northwards where the reindeer, musk ox, wolf, arctic fox, and white bear now live.† But we find in some parts of the drift evidence of a conflicting character, such as may suggest the idea of the occasional intercalation of more genial seasons of sufficient duration to allow of the migration and temporary settlement of species coming from another and more southern province of mammalia, so that their remains were buried in river gravels at the same level as the bones of animals and shells of a more northern climate. If we allow a vast lapse of ages for the accumulation of the drift, we may take for granted that there must have been such changes in climate, owing chiefly to geographical conditions to be explained in the twelfth chapter, and perhaps sometimes modified by astronomical causes, which will be treated of in the thirteenth chapter. Bones of the hippopotamus, of a species closely allied to that now inhabiting the Nile, are often accompanied in the valley of the Thames and elsewhere

* Ant. of Man, 3rd edit., Appendix, p. 5.

† See an admirable essay by E. Forbes, in the Memoirs of Geol. Survey of Great Brit., vol. i. p. 336. 1846.

by a species of bivalve shell, *Cyrena* (*Corbicula*) *fluminalis*, now living in the Nile and ranging through a great part of Asia as far as Tibet, but quite extinct in the rivers of Europe. Imbedded in the same alluvium with this shell, we find at Grays in Essex, *Unio littoralis*, a mussel no longer British, but abounding in France in rivers more southern than the Thames. The *Hydrobia marginata* is also a shell sometimes met with in the drift, a species now inhabiting more southern latitudes in Europe. The kind of elephant and rhinoceros accompanying the Cyrena at Grays (*E. antiquus* and *R. megarhinus*) are not the same as the mammoth and rhinoceros which occur with their flesh in the ice and frozen mud of Siberia, or in those assemblages of mammalia which have an arctic character in the drift of England, France, and Germany. Some zoologists conjecture that the fossil species of hippopotamus was fitted for a cold climate, but it seems more probable that when the temperature of the river-water was congenial to the Cyrena above mentioned, it was also suited to the hippopotamus.

Glacial Epoch.—The next step of our retrospect carries us back to what has been called the Glacial Epoch, which, though for the most part anterior to the valley-drifts and cave deposits of the palæolithic age above mentioned, was still so closely connected with that period that we cannot easily draw a line of demarcation between them. The dispersion of large angular fragments of rock, called erratics, over the northern parts of Europe and North America, far from the nearest parent rocks from which they could have been derived, had long presented a difficult enigma to geologists before it began to be suspected that they might have been transported by ice, either on land or by floating bergs, at a period when large parts of the present continents were submerged beneath the sea.

These blocks are observed to extend in Europe as far south as lat. 50°, and still farther in America, or to lat. 40°. It was remarked that some of them were polished, and striated on one or more of their sides in a manner strictly analogous to stones imbedded in the moraines of existing glaciers in the Alps. In many areas covered with them both in America

and Europe, the underlying solid rocks were seen to be marked by similar scratches and rectilinear furrows, their direction usually coinciding with the course which the erratics themselves had taken. As both the smoothing and striation of the transported fragments and the surfaces of the rocks *in situ* were identical in character with those recently produced by existing glaciers, it was at length admitted (but not till after the point had been controverted for a quarter of a century, and in direct opposition to the opinion of the earlier geologists) that the climate which preceded the historical was not only colder as far south as lat. 50° in Europe, and even to 46° in the Alps, but was marked by an intensity of cold quite unequalled at present in corresponding latitudes, whether in the northern or southern hemisphere.

Some marine shells of living arctic species, and which no longer frequent the seas of temperate latitudes, were found in the glacial drift of Scotland and North America; so that evidence derived from the organic as well as from the inorganic world conspired to establish the former prevalence of a climate now proper to polar latitudes throughout a great part of Europe.

By means of these drifts, and others containing assemblages of marine shells more or less northern in character, great oscillations in the level of the land since the commencement of the Glacial Epoch were proved to have taken place. The change of level in Scotland, as demonstrated by this kind of proof, amounts to more than 500 feet, in some parts of England, as in Cheshire, to 1,300, and in North Wales to 1,400 feet; these movements having all occurred in post-tertiary times, or within the period of the living testacea. But Professor Ramsay infers, from the position of the stratified drifts of the Glacial Period in North Wales, that the full extent of the vertical movement which brought about first the submergence and then the re-emergence of the land exceeded 2,000 feet.

Inter-Glacial Periods.—Without entering in this place into the proofs of two continental periods in Britain during the Glacial Epoch, separated from each other by a long interval of submergence, during which Great Britain and

Ireland were in the state of an archipelago of small islands, it may be affirmed that the excessive cold lasted for a long series of ages, although not always with the same intensity. As illustrative of the fact of the cold having been intermitted or sometimes mitigated for a season, may be mentioned what the late Hugh Miller called 'striated pavements.' These consist of horizontal surfaces of boulder clay, in which the imbedded boulders are seen to have been subjected to a process of abrasion similar to that which the solid rock below had previously undergone. In such instances large stones or blocks fixed in the clay have not only their original and independent striæ, but have subsequently suffered a new striation which is parallel and persistent across them all. These appearances have been observed on the shores of the Firth of Forth, below Edinburgh, and in other places, both on the east and west coasts of Scotland, and on the shores of the Solway in England. Some examples of this second striation may have been due to the friction of icebergs on the bed of the sea during a period of submergence; others to a second advance of land glaciers over moraines of older date.*

M. Morlot and others have adduced abundant evidence of two glacial periods in the Alps, during the first of which the glaciers attained colossal dimensions, filling the great valley of Switzerland with ice, which reached from the Alps to the Jura, while on the southern side of the great chain other contemporaneous glaciers invaded the plains of the Po, where they have left moraines of truly gigantic dimensions. After these huge glaciers had retreated for a time, they advanced again, and though not on so large a scale, they still vastly exceeded in size the largest Swiss glaciers of our day. The interval of milder weather, marked by the decrease of snow and ice in the Alps, has been called by Prof. Heer the Inter-glacial Period, which must have been of considerable duration, for it gave time for the accumulation of dense beds of lignite, like those at Dürnten, and other localities near Zürich. During this intercalated

* A. Geikie, Phenomena of Glacial Drift of Scotland, p. 66, who cites Messrs. C. Maclaren, Hugh Miller, Milne-Home, and Smith of Jordan-hill

series of warmer seasons the climate is supposed by Heer to have closely resembled that now experienced in Switzerland. He infers this from the fossil flora of the lignite, especially from the occurrence of cones of the Scotch and spruce firs, and the leaves of the oak and yew, all of living species, as well as from the seeds of certain marsh plants. The insects also, and the fresh-water shells, tell the same tale. Among the mammalia occurring in the lignite-bearing shales of Dürnten are an elephant (*E. antiquus*), an extinct species of bear (*Ursus spelæus*), and a rhinoceros different from *R. tichorhinus*. That the formation of the shale and lignite containing the above-mentioned remains was both preceded and followed by periods of greater cold is shown on the one hand by the polished and striated rock surfaces on which the shale and lignite rest, and on the other by the large size of the erratic blocks which are superimposed upon them.*

In England the lignite, or Forest Bed as it is called, of Cromer, on the Norfolk coast, presents a singular analogy to that of Dürnten above described. It contains in like manner the cones of the spruce and the Scotch fir, and the seeds and leaves of marsh plants, and some shells and mammalia in common with the Swiss deposit. It was also preceded and followed by a period of greater cold. The antecedence of a colder climate is proved by the arctic character of a large proportion of the shells of living species included in the marine strata of Chillesford, near Ipswich, in lat. 52° N., which, according to the observations of Messrs. Prestwich and Searles Wood, are more ancient than the forest or lignite bed. On the other hand, that the Forest Bed of Cromer was followed by an era of severe cold, is shown by the fact that it underlies the great mass of glacial drift, which is in part unstratified, and contains boulders and angular blocks transported from great distances, and some of them exhibiting polished and striated surfaces.†

We are by no means sufficiently advanced in our interpretation of the monuments of the Glacial Epoch, and of the long succession of events which mark its history, to be able to affirm that the inter-glacial periods of Dürnten and

* Heer, Urwelt der Schweiz, p. 532. † Antiquity of Man, pp. 212–218.

Cromer, above mentioned, were contemporaneous; but they both of them alike demonstrate that there were oscillations of temperature in the course of that long epoch of cold. There were also great changes, as before stated, in the form of the earth's crust, many movements of upheaval and subsidence, and many conversions of sea into land, and land into sea, during the Glacial Epoch. We are in danger of underrating the quantity of time during which the cold prevailed; because, in proportion as the ice increases in thickness, it cancels all marks of antecedent glaciation. The grinding action of the great ice-sheet which now envelops Greenland illustrates this process. Were that ice to melt, it would require as much skill to detect the evidence of the moraines and erratics of an older time as in the case of a palimpsest to recover the work of the original author, which had been purposely washed out to make room for the new manuscript.

From the foregoing observations, the reader will learn that the prevalence of a colder climate at the close of the Tertiary, and in the early part of the Post-tertiary periods, has been inferred from two perfectly independent sources of evidence, the first of which may be called inorganic, such as erratic blocks, moraines, and the polishing and striation of rocks; and the second, organic, such as the arctic character of the shells found in the drift of temperate regions. But another or third proof was also pointed out by the late Edward Forbes, as derivable from the present geographical distribution of animals and plants in mountainous regions, especially in high latitudes, in Europe and North America. After the refrigeration of the northern hemisphere had lasted for thousands of years, an arctic fauna and flora must have inhabited the lower lands of temperate latitudes, at a time when the more elevated parts of the same country were buried under permanent snow and ice. On the return of a warmer climate, when the excess of snow was gradually reduced, the arctic species of plants, insects, birds, and mammalia, would ascend to the higher parts of each continent, while the plains would be invaded by species migrating from the south. Hence an arctic fauna and flora, which

once extended from polar latitudes far to the south, ranging continuously over what are now the temperate regions of America, Europe, and Asia, became restricted to the summits of the highest chains, such as the Alps or the mountains of Scotland, Scandinavia, and New Hampshire in the United States. The identity of the species now found in isolated patches at or near the tops of so many widely separated mountains would have been inexplicable, had not the geologist discovered that about the close of the Tertiary èra there was a glacial epoch instead of that warm temperature formerly assigned to times preceding the historical.*

British Pliocene strata, showing transition from warmer to colder climate.—When we pass beyond the ages when a colder temperature prevailed, and, receding a step farther into the past, examine the fossils of the British Pliocene strata, we find in the earliest or lowest members of them very interesting proofs of a climate warmer than that now prevailing in England, and more resembling that of the Mediterranean. As we ascend in the series, the shells of successive groups of strata, provincially called crag in Norfolk and Suffolk, are seen to consist less and less of southern species, while the number of northern forms is always augmenting, until in the uppermost or newest groups, in which almost all the shells are of living species, the fauna is very arctic in character, and that even in the 52nd and 54th degree of North latitude.†

Pliocene strata of Italy.—The Pliocene strata of Italy, commonly called sub-Apennine, point in like manner to a warm climate. Such, for example, of the fossil shells of Sienna, Parma, and Asti as are of species now inhabiting the Mediterranean and the Indian Ocean, correspond in size with individuals taken from the warmer of the two seas, those now surviving in the Mediterranean appearing to be stunted in their growth, as if deprived of the favourable conditions which the Pliocene Period afforded them in Italy.‡

* Edward Forbes' Memoirs of Geol. Survey, vol. i. p. 399. 1846.

† See above, p. 195; also Elements of Geol., pp. 198, 204, edit. of 1865; and Student's Elements, 1871, p. 169.

‡ Professors Guidotti of Parma, and Bonelli of Turin, pointed out to me, in 1828, many examples in confirmation of this point.

It may also be observed, that the extinct species of the sub-Apennine fauna belong, in great part, to forms which are now most largely developed in equatorial regions, as, for example, the genera Cancellaria, Cassidaria, Pleurotoma, and Cypræa.

Warm climate of Upper Miocene Period.—The next step in our retrospective survey carries us to the monuments of the Upper Miocene Period. In the marine formations of this era a third or more of the testacea belong to living species, not a few of which are now inhabitants of more southern latitudes, and of the associated fossil species unknown as living some belong to genera now characteristic of more southern climates. Although in Great Britain Upper Miocene strata are entirely wanting, they occur in Belgium and North Germany, where they contain shells of the genera Conus, Cancellaria, and Oliva—forms all of them foreign to our seas as well as to our British Pliocene deposits, and proper to and indicative of a higher temperature.

The French strata of the same age, called the Faluns of the Loire, point to similar inferences, and, like the contemporaneous beds of the Vienna basin, contain some fossil shells of species now living in Senegal or off the western coast of Africa. The Upper Miocene flora and fauna of the whole of Central Europe afford unmistakable evidence of a climate approaching that now only experienced in sub-tropical regions. In one of the newest deposits of this Upper Miocene formation, Professor Heer has detected, at Œninghen, in Switzerland, the leaves, fruits, and sometimes flowers of about 500 species of plants, in which we find a near resemblance to the flora of the Carolinas and other Southern States of the American Union. After selecting 483 of these species as capable of comparison, specifically or generically, with plants now living, he finds that 131 are such as might be referred to the temperate zone, 266 to a sub-tropical, and 85 to a tropical latitude. In the present state of the globe, the island of Madeira presents the nearest approach to such a flora. The proportion of arborescent as compared to the herbaceous plants is very great, and among the former the predominance of evergreens implies an absence of severe

winter cold. A rich insect fauna, such as belongs to a warm climate, is also attested by the great number of the species of those genera which are most easily preservable in a fossil state. The reptiles which play so insignificant a part in the Pliocene fauna of Central and Northern Europe form a more conspicuous feature in these Miocene formations. At Œninghen there are two tortoises and three species of salamanders, one of them more gigantic in size than the living species of Japan. Bones of the monkey tribe are also met with in Upper Miocene strata near the foot of the Pyrenees in France. Among them is a gibbon, or long-armed ape, equal to man in stature, and the femur of a large species of this family has been detected by Dr. Kaup in strata of the same age at Eppelsheim, near Darmstadt, in a latitude which corresponds to the southern part of Cornwall.* In Greece also, near Athens, the remains of Upper Miocene quadrumana have been met with, confirming the inferences as to the warm temperature of Europe previously drawn by naturalists from the fossils, shells, and corals of Touraine, Bordeaux, and Vienna.

Fossils of the Siwâlik Hills.—It is a matter of no small interest to have learnt that when the climate of Europe was sub-tropical, a still greater heat prevailed nearer the equator. Our best information on this subject is afforded by the investigations of Dr. Falconer and Sir Proby Cautley, who collected, in 1837, a large number of fossil remains from the Siwâlik hills, which skirt the southern base of the Himalaya to the west of the river Jumna. Here the abundance and variety of the fossil mammalia is prodigious, there being no less than seven species of proboscidians of the genera mastodon and elephant. With these a huge extinct four-horned ruminant, called Sivatherium, was found, as well as a camel, a hippopotamus, a hyena, and more than one species of monkey. The associated reptiles also bear witness to a temperature higher than that of any European strata of the same date, for, besides some extinct saurians larger than any now existing, we find among them the living crocodile of the Ganges, *C. biporcatus*, and the living gavial of the same river,

* Owen, Geol. Trans., 1862, and Geologist, 1862, p. 247.

besides a colossal extinct tortoise, of which the shell was no less than eight feet in diameter.

Upper Miocene strata of the West Indies.—If again we turn to the Upper Miocene formations of the West Indies, those, for example, of Antigua, San Domingo, and Jamaica, we discover in them species of corals similar to those found in beds of the same age at Vienna, Bordeaux, and Turin, and some of which, as Dr. Duncan has shown (1863), have a near affinity to species now living in the Pacific (South Sea), Indian Ocean, and Red Sea. They lead irresistibly to the opinion that there was a much greater analogy in those ages than there is now between the temperature of the West Indies in lat. 18° N. and that of Europe in lat. 48° N. *

Dr. Duncan concludes therefore, not only that there was no Isthmus of Panama, but also that there was no great barrier of land or Atlantic continent separating the Miocene seas of Europe from the contemporaneous seas of the West Indies. Already in 1850 Mr. John Carrick Moore had pointed out that certain Tertiary shells of San Domingo exhibited affinities to the Miocene shells of Europe,† and that although such of the San Domingo species as agreed with the living were chiefly Atlantic forms, there were some so closely allied to the existing Pacific fauna as to lead him to infer that there had been a channel in Miocene times through what is now the Isthmus of Panama, by which the mollusca could have migrated from one ocean to the other. Such an hypothesis, he observes, will be the more readily accepted when we consider that the summit-level of the Panama Railway above the sea is only 250 feet, and that the isthmus nowhere attains an elevation exceeding 1,000 feet, which is not half the height to which the marine Miocene strata of San Domingo have been uplifted since their deposition.

Mr. Etheridge has inferred from these and other researches that the separation from the Pacific dates from the commencement of the upheaval of the Miocene deposits of the Isthmus of Panama, which upheaval probably was not completed until the Pliocene age.

* Duncan, West Indian Corals, Quart. Geol. Journ., p. 455, vol. xix. 1863.

† Quart. Geol. Journ., 1850, vol. vi. p. 43.

Lower Miocene strata.—By referring to our table at p. 135, the reader will see that the Lower Miocene strata come next in order as we recede from the more modern formations to those of higher antiquity. They contain scarcely any living species of shells or plants, yet so many of their fossil remains are common to them and the Upper Miocene formation, that this fact alone would lead us to expect that they would afford indications of a warm climate. Such an anticipation is more than confirmed, both by negative and positive evidence; for, in the first place, nearly all the genera of plants which in the Œninghen beds were mentioned as characteristic of temperate latitudes, are wanting in the Lower Miocene, while the tropical forms are more numerous. Among these last are palms of the genus Phœnicites, closely allied to the date-palm. About 80 other plants are enumerated by Heer, all of which would be cut off by such a winter as now prevails in Central and Southern Europe. Ligneous plants constitute two-thirds of the flora, and the preponderance of evergreens exceeds even that observed in the Upper Miocene strata of Œninghen. There are also more reptiles in these older beds, and some of considerable size. Among them are no less than three crocodiles and fifteen land and fresh-water tortoises.*

Miocene fossil flora of Arctic latitudes.—The Lower Miocene flora has been traced from Italy northwards to Devonshire, and even to Iceland. In these high latitudes, however, the tropical and sub-tropical genera disappear, though the vine, tulip-tree, and some other forms indicate a temperature 15° or 20° Fahr. warmer than that now belonging to the same countries.†

We find in certain beds of lignite or surturbrand in Iceland, recently examined by Professor Heer, an assemblage of fossil plants resembling in many respects that of Œninghen, before mentioned. Though not of so sub-tropical a character, they imply a warmth as much exceeding that now enjoyed in Iceland as did the temperature of the Upper Miocene flora

* Heer, Urwelt der Schweiz, p. 401.

† Heer and Gaudin, Climat du Pays tertiaire, p. 174, 207.

of Central Europe surpass that of the vegetation now proper to the same region.*

The extent to which the Miocene flora flourished within the Arctic circle, even as far towards the pole as our exploring expeditions have penetrated, has been clearly pointed out by Professor Heer, in an important treatise on the fossil flora of the Arctic regions.† In the numerous plates which illustrate this work, we see figures of more than 60 species of North Greenland fossil plants found opposite Disco Island, lat. 70° N. Among them are several species of Sequoia (*Wellingtonia*), with their male catkins and cones, agreeing specifically with Lower Miocene plants of Switzerland, Germany, or England. There are also seven other conifers, four poplars, two willows, three species of beech, four of oak (some of which have leaves half a foot long), a plane-tree, a walnut, a plum or prunus, a buckthorn, an andromeda, a daphnogene with large leathery leaves, and several other evergreens, some of extinct genera. The large-leaved trees imply, according to Heer, a high summer temperature, while the evergreens exclude the idea of a very cold winter. That these and other fossil plants from arctic localities really lived on the spot, and were not drifted thither by marine currents, is proved by the quantity of leaves pressed together, and in some cases associated with fruits, also by the marsh plants which accompany them, and by the upright trees with roots which were seen by Captain Inglefield and by Rink.

Still farther north in Spitzbergen, in lat. 78° 56′ N., no less than 95 species of plants are described by Heer, many of them agreeing specifically with North Greenland fossils. In this flora we observe Taxodium of two species, a hazel, poplar, alder, beech, plane-tree, lime (*Tilia*), and a potamogeton, which last indicates a fresh-water formation, accumulated on the spot. Such a vigorous growth of fossil trees, in a country within 12° of the pole, where there are now scarcely

* Heer and Gaudin, Climat du Pays tertiaire, p. 178.

† Heer, Flora Fossilis Arctica, with 40 illustrative plates, containing figures of fossil plants, collected by M. Nordenskiold, and Captain Sir L. McClintock, Sir R. Maclure, Colomb, Inglefield, and others.

any shrubs except a dwarf willow, and where there are only a few herbaceous and cryptogamous plants, most of the surface being covered with snow and ice, is truly remarkable. When the fossils are compared with the Miocene species of Central Europe and Italy, many of them are found to be the same, and it is clear that the climate was not only much warmer than now, but the temperature of Europe and the Arctic circle was much less contrasted; nevertheless, the flora of Spitzbergen was by no means so sub-tropical at the era alluded to as was that of Switzerland, Germany, and Devonshire, for in the Lower Miocene period the difference of latitude made itself felt as now, although in a less degree. Professor Heer infers, with great probability, that pines, alders, poplars, willows, and other hardy genera reached the pole itself in Miocene times, if there was land there, because they range at present from 4 to 10 degrees farther north than the Taxodium, beech, plane and lime, which accompany them in a fossil state in the same formation at Spitzbergen. Some of the last-mentioned genera are in a higher latitude in Spitzbergen, by 8, 17, and 23 degrees, than the living representatives of the same genera. We cannot hesitate, therefore, to conclude that in Miocene times, when this vegetation flourished in Spitzbergen, North Greenland, and on the Mackenzie river, as well as Banks Land, and other circumpolar countries, there was no snow in the arctic regions, except on the summit of high mountains, and even there perhaps not lasting throughout the year.

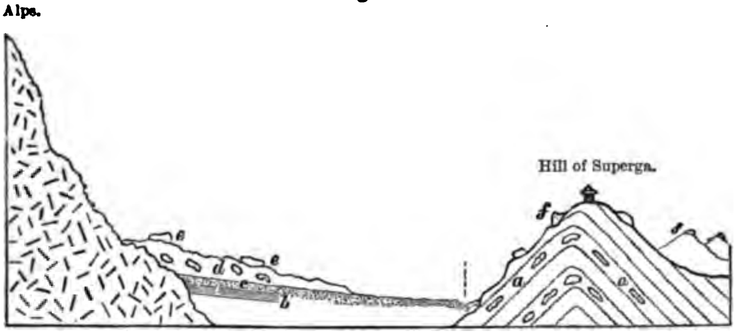
Ice-action in the Miocene Period.—If it be asked whether in the entire Miocene series there are no indications of intercalated spells of colder climate, like the glacial episode before mentioned as intervening between the older Pliocene and the modern eras, I may reply that there are none which can at present be established on organic evidence; but our geological records are far too fragmentary to entitle us positively to assume that, in the course of so vast a succession of ages, there were no oscillations of temperature analogous to those which certainly occurred between the close of the Newer Pliocene period and our own time. Professor Ramsay, who has so successfully devoted much time

and thought to the search for indications of glacial action in remote eras, reminds us that a geologist must expect to encounter great difficulties in such investigations. If, at some future era, when large portions of the existing continents shall have been submerged and overspread with marine strata, and other parts of them destroyed by denudation, we should have the task assigned to us of detecting those spots where ancient land-surfaces had escaped destruction, or where erratic blocks and moraines of glaciers were extant, we might well despair of success. It rarely happens that we have opportunities of examining terrestrial surfaces of high antiquity, and when visible, their extent is always very limited. In the majority of cases they will consist of rocks incapable of receiving and preserving a glacial polish and striation. The least evanescent of the proofs of ice-action, which our era is likely to transmit to future ages, are, unquestionably, those large angular erratics which have been carried to great distances from their parent rocks; and wherever such masses occur in older strata they deserve particular attention. I shall proceed, therefore, to describe a formation of Miocene date, which I have myself examined, in which the position and size of the included blocks is such as to make it impossible at present to account for their transportation by any other cause than the buoyant power of ice.

The marine deposits alluded to consist of strata of sandstone and conglomerate, and constitute a member of the Miocene formation of the Collina of Turin, a chain of hills in the suburbs of the capital of Piedmont, on the brow of which stands the church of the Superga. These strata have long been celebrated for containing a plentiful store of fossil shells of the same species as those of the faluns of Touraine, Bordeaux, and Vienna. The annexed diagram will give the reader some idea of the position of this conglomerate (*a*), which is highly inclined and conformable to the other strata which dip on each side to the north-west and south-east from the axis of the chain. I examined the district in 1857, in company with Signor Gastaldi, one of the ablest of the Italian geologists, and one well versed in glacial phenomena.

On this occasion I satisfied myself that Signor Gastaldi was right in supposing that the large blocks *f f*, lying on the surface of the hills, had been washed out of the beds *a a*, by the same action which has hollowed out the valleys.* In other words, they have not been brought from a distance, as was once supposed, during the more modern or Post-pliocene Glacial period, like the erratics *e*, which rest on the moraine *d*, but have been washed out of the Miocene beds in the immediate neighbourhood, viz., the conglomerate *a*. This last

Fig. 8.



Section from the Alps to the Hill of the Superga, showing the position of the Miocene erratic blocks.

a. Conglomerates of Miocene age with large blocks.
b. Marine sub-Apennine or Pliocene strata.
c. Diluvium or ancient alluvium of various ages, some of it below the moraine *d*.
d. Moraine of Ivrea of the Glacial period with erratic blocks.
e. Erratic blocks lying on the moraine *d*.
f. Miocene blocks washed out of the conglomerate *a*, and scattered over the hills of the Superga chain.
N.B.—The distance from the Alps to the Superga is about thirty miles.

is part of a regular series of strata, composed chiefly of sand of various degrees of coarseness, and of gravel, in which are rolled pebbles of greenstone (or diorite), limestone, porphyry, and some other rocks. Among them we occasionally meet with fragments of serpentine and greenstone, of enormous size, one of which I ascertained by measurement to be 14 feet in its longest diameter. Signor Gastaldi has seen another in the same formation, 26 feet long; they are angular,

* Gastaldi, Sui Conglomerati Mioceni del Piemonte. 1861.

and several of those which I saw, exhibited some faint striæ and had one of their sides polished, in a manner much resembling that produced by glacial action. The whole thickness of the beds through which these blocks are dispersed varies from 100 to 150 feet. As yet they have yielded no organic remains, but they are covered by strata containing shells of the Upper Miocene formation, and they rest on Lower Miocene strata for the most part of fresh-water origin. The fauna and flora, both of the overlying and underlying rocks, have the same sub-tropical character as those of Miocene date in Switzerland and in Central Europe generally. Hence the hypothesis of the transport of such huge blocks by ice-action has naturally been resorted to most unwillingly, but in the present state of our knowledge it is the only one which appears tenable. The beds of sandstone alternating with those in which the blocks are enveloped exhibit no signs of having been tumultuously accumulated as by a flood. The erratics seem rather to have fallen quietly into their places. The nearest spots where any similar serpentine and greenstone occur are about twenty miles to the westward, but there has been so much subsidence of the country during the Miocene period, so much subsequent deposition of overlying miocene, pliocene, and alluvial deposits, and such changes in physical geography, that we cannot decide with any certainty as to the proximity or distance of the spots from which the blocks may have come. The absence of organic remains may possibly imply a sea chilled by floating ice, or by a cold current from the north; but such an hypothesis is not very satisfactory, because the thickness attained by the conglomerate in some parts of Piedmont is very great, far exceeding that seen in the vicinity of Turin. We must conclude, therefore, that its accumulation occupied a great lapse of time, and if so, it is difficult to understand why there are no organic remains in it: for although the temporary influx of a cold current might well be supposed to annihilate a fauna fitted for a warmer sea, yet the long continuance of such a current would naturally fit the region for species such as thrive in the seas of colder latitudes. Perhaps a lofty mountain, with a glacier reaching the sea, would be the least objectionable

hypothesis, since in Patagonia there is a glacier descending from the Andes in Eyre Sound, in the latitude of Paris, and another in the neighbouring Gulf of Penas, lat. 46° 50′ (or the latitude of the Bernese Alps), both of which convey large erratic blocks to the Pacific, into which they are floated by numerous icebergs of large size.

Eocene Fauna and Flora.—In the flora of the upper members of this great series, we find in the neighbourhood of Paris and in the Isle of Wight, some plants which, like the palmetto, attest a warmer temperature. Among the accompanying reptiles, there are many crocodiles and tortoises, such as we now only meet with in more southern regions. In the Middle Eocene, as in the calcaire grossier, for example, near Paris, the marine testaceous fauna is richer and more varied than that now proper to seas so far north. The flora of the same division of the Tertiary period, as, for example, that of Alum Bay in the Isle of Wight, of Monte Bolca in the North of Italy, or that of Aix en Provence in the South of France, comprises species and genera having a great affinity to Lower Miocene forms, but departing farther than do these from the modern European type, and, according to Heer, resembling in many respects plants of the tropical regions of Australia and India.

The nummulitic formation of this era is of world-wide extent, and contains many corals of large size, of genera now common in tropical seas, some of the same fossil species ranging from Sinde in India to the West Indies.

If, lastly, we turn to the Lower Eocene strata, we find in the London clay of the Isle of Sheppey fossil fruits of the cocoa-nut, screw-pine, and custard-apple, reminding us of the hottest parts of the globe; and in the same beds are six species of *Nautilus*, and other genera of shells, such as Conus, Voluta, and Cancellaria, now only met with in warmer seas. The fish also of the same strata, of which 50 species have been described by Agassiz, are declared by him to be characteristic of hotter climates, and among the reptiles are sea-snakes, crocodiles, and several species of turtle.

Supposed signs of ice-action in the Eocene Period.—In a bed of coarse conglomerate of the Eocene period in the Alps,

phenomena in many respects analogous to those of the neighbourhood of Turin present themselves. This conglomerate is a subordinate member of that vast deposit of sandstone and shale which is provincially called 'flysch' and 'nagelflue,' and which, by its position (for it is devoid of organic remains), seems referable to the middle or 'nummulitic' portion of the great Eocene series. The well-known 'Vienna sandstone' is a member of this flysch, which extends for 300 miles at least, east and west, from Vienna to Switzerland, along the northern flanks of the Alps, and is again seen in the south, near Genoa, and in several parts of the Apennines, where it is called by the Italians 'macigno.' Its thickness is very great, amounting to several thousand feet, and occasionally, according to some authorities, to 6,000 feet. It is often finely stratified, and singularly barren of fossil remains, although in a few places it contains fucoids. Here and there, as in the Sihlthal, near the lake of Zürich, and in the Toggenburg in St. Gall, large blocks are enclosed in it, some of them angular and others rounded. These blocks are occasionally of limestone, and contain ammonites and other fossils of the oolitic and liassic formations, as described by Dr. Bachmann.* Blocks also of a red variety of granite of a peculiar composition, not known *in situ* in any part of the Alps, occur in the same conglomerate of the flysch. In several places the blocks are 10 feet long, but at Habkeren, on the north side of the lake of Thun, many are seen of enormous dimensions, one of them being 105 feet in length, 90 in breadth, and 45 in height. They have lost their edges, either by friction or decomposition, but are not polished or striated.

There has been a lively discussion as to whether the largest of the above-mentioned Habkeren blocks came out of the flysch, or were simply erratics of the Glacial period; † but Escher von der Linth, Studer, Rütimeyer, and Bachmann are clearly of opinion that they have been washed out of the coarse conglomerate. The flysch of Bolgen, near

* Bachmann, Petrifakten und erratische Jurablöcke im Flysch des Sihlthals und Toggenburg.

† Murchison, Structure of Alps, Quart. Geol. Journ., vol. v. 1849.

Sonthofen, also contains foreign blocks of considerable size, and similar masses, as I am informed by Professor Suess, occur in Tertiary strata of the same age in the Carpathians and Apennines, but neither on them nor on any others have any glacial striæ been as yet observed. We have to account not only for the wonderful size of the granitic rocks, varying from 10 to 100 feet in diameter, but for the distance which they have travelled, which seems to be implied by our inability to refer them to any known source. They are distinguishable by their mineral character from all granitic erratics of the true or modern glacial period, such as are strewed over the surface of those districts of Switzerland where there is no outcrop of flysch conglomerate. The hypothesis that these huge masses were transported to their present sites by glaciers or floating ice, has been always objected to on the ground that the Eocene strata of nummulitic age in Switzerland, as well as in other parts of Europe, contain genera of fossil plants and animals characteristic of a warm climate. It has been particularly remarked by M. Desor, that the strata most nearly associated with the flysch in the Alps are rich in echinoderms of the Spatangus family, which have a decidedly tropical aspect. The entire absence of shells, or of organic remains generally, may perhaps be thought to favour a glacial origin for the flysch, but this negative character is too common in strata of every age to be of much value, except in connection with other proofs of intense cold. Nor must we disguise from ourselves the fact, that in the seas of polar regions where icebergs abound at present there is by no means any dearth of animal life. On the other hand, the regular stratification and even fine lamination of large portions of the flysch cannot be said to be inconsistent with a glacial origin, for on the Norfolk coast we see thinly laminated clays devoid of organic remains forming an integral part of unquestionable glacial deposits.

The great thickness of the flysch, and the fucoids preserved in a few beds of it, lead to the conclusion that it was of marine origin. To imagine icebergs carrying such huge fragments of stone in so southern a latitude, and at a period

immediately preceded and followed by the signs of a warm climate, is one of the most perplexing enigmas which the geologist has yet been called upon to solve. It would perhaps be most in accordance with existing analogies to suppose a mountainous island occupying the site of the Austrian and Swiss Alps from which glaciers descended to the sea. For in the southern part of New Zealand, between latitudes 43° and 44° S. in the southern (formerly called the middle) island, glaciers coming from Mount Cook, the loftiest mountain of a snow-covered chain, reach to within 500 feet of the sea, and the same region is inhabited not only by tree-ferns, but by an Areca palm. These plants of tropical aspect are now seen flourishing in this district, very near to moraines and angular fragments of stone recently brought down by ice from the higher regions. But we shall see (Chap. XVI.) that icebergs, sometimes carrying huge erratic blocks, float at the present time in both hemispheres to parts of the sea hundreds of miles from land, in latitudes nearer the equator than the Swiss Alps: we ought not, therefore, to wonder at the occurrence of erratics in any stratum in the temperate regions of the globe, at periods when the temperature resembled that of our time, nor consider them as by any means implying an intensity of cold equalling that of the so-called Glacial Epoch.

CHAPTER XI.

FORMER VICISSITUDES IN CLIMATE—*continued.*

WARM CLIMATE IMPLIED BY THE FOSSILS OF THE CHALK—CRETACEOUS REPTILES—HOW FAR EXTINCT GENERA AND ORDERS MAY ENABLE US TO INFER THE TEMPERATURE OF ANCIENT CLIMATES—EVIDENCE OF FLOATING ICE IN THE SEA OF THE WHITE CHALK OF ENGLAND—WARM CLIMATE OF THE OOLITIC AND TRIASSIC PERIODS—WIDE RANGE OF THE SAME FAUNA FROM SOUTH TO NORTH—ABUNDANCE AND WIDE RANGE OF REPTILES IMPLIES A GENERAL ABSENCE OF SEVERE COLD—THE NON-EXISTENCE OF CONTEMPORARY MAMMALIA WILL NOT EXPLAIN THE PREDOMINANCE OF REPTILES IN HIGH LATITUDES—PERMIAN FOSSILS—SUPPOSED SIGNS OF ICE-ACTION IN THE PERMIAN PERIOD—UNIFORMITY OF THE FOSSIL FLORA OVER WIDE AREAS—MELVILLE ISLAND COAL-PLANTS—HOW FAR THE ABSENCE OF FLOWERING PLANTS VITIATES OUR INFERENCES AS TO ANCIENT CLIMATES—WHETHER THE ATMOSPHERE WAS SURCHARGED WITH CARBONIC ACID IN THE COAL PERIOD—FOSSIL SHELLS AND CORALS OF THE CARBONIFEROUS STRATA—CLIMATE IMPLIED BY THE REPTILES OR AMPHIBIA OF THE COAL—DEVONIAN PERIOD, AND SUPPOSED SIGNS OF ICE-ACTION OF THAT ERA CONSIDERED—CLIMATE OF THE SILURIAN PERIOD—CONCLUDING REMARKS ON THE CLIMATES OF THE TERTIARY, SECONDARY, AND PRIMARY EPOCHS.

IN the last chapter I endeavoured to trace back the history of the changes of climate from modern times to the Eocene period, and we found, that before we had carried back our retrospect as far as the Newer Pliocene deposits, proofs already presented themselves, both organic and inorganic, of a temperature much colder than that now prevailing in European latitudes. Although this Glacial epoch, as it has been called, lasted for thousands, if not hundreds of thousands of years, it was of so modern a geological date as to belong almost exclusively to the time when the mollusca were the same as those now living. The geographical range only of species was different, because an arctic fauna was enabled by aid of the cold to invade the temperate latitudes. An examination of the fossils of the Pliocene, Miocene, and Eocene strata, viewed successively in the order of their

higher antiquity, afforded us evidence of a temperature continually increasing, in proportion as we receded farther from the Glacial epoch. If, in certain localities in or near the Alps, some huge transported fragments of rock, enclosed in miocene and eocene conglomerates, seemed to require the aid of ice to bring them into the sites they now occupy, a local combination of geographical circumstances may perhaps be conceived, which might account for such exceptional cases without requiring a general refrigeration of climate at the times alluded to, or, still more probably, floating icebergs may, as suggested (p. 210) in explanation of the Habkeren erratics in the Alps, have brought large fragments from a great distance without requiring us to suppose a lower temperature than that now prevailing on the earth.

Warm climate implied by the fossils of the Chalk or Upper Cretaceous.—When we pass beyond the gap which divides the Tertiary from the Secondary formations, between which there are very few forms in common, we observe in the cretaceous strata signs of a warm climate similar to those previously derived from tertiary plants, shells, corals, and reptiles. Many of the principal members of this cretaceous series have been traced from the 57th degree of latitude in the northern hemisphere to districts which approach within 10 or 12 degrees of the equator, as at Pondicherry, Verdachellum, and Trichinopoly. In these countries deposits occur, which by their ammonites and many other mollusca were recognised by the late Edward Forbes as belonging to beds, some of them corresponding to our English Gault, and others to strata which immediately overlie and underlie that formation.* In these Indian formations are found shells of the genera Cypræa, Oliva, Triton, Pyrula, Nerita, and Voluta, which belong to forms now characterising tropical seas, and some of which only made their first appearance in European latitudes in the uppermost or Maestricht chalk. The geographical birthplace, says Forbes, of these genera seems to have been in the tropics before the Tertiary period, during which last they made a great figure in Europe throughout

* See Report on Fossils collected by C. J. Kaye, Esq., and Rev. W. H. Egerton, Quart. Geol. Journ., 1845, vol. i. p. 79.

Eocene and Miocene times, retreating again southwards in the Newer Pliocene era, when the cold of the approaching Glacial epoch had begun to make itself felt.

The plants of the Upper Cretaceous formation of Europe so far as they are known, have such an affinity with the Eocene flora as to point in the same direction in regard to the existence of a high temperature. They contain a large number of dicotyledonous angiosperms, whereas the Lower Cretaceous rocks are characterised by the absence of these last, and by a predominance of cycads and of conifers of an araucarian type, and of ferns referred by some botanists to genera which also favour the hypothesis of a warm climate.

In reasoning on the organic remains of the Upper Miocene strata of Central and Southern Europe, we had the advantage of drawing our inferences as to the high temperature of the atmosphere and ocean from shells, one-third of which were of living species, while our conclusions were confirmed by the discovery of contemporaneous genera of plants, insects, and corals, as well as of apes and monkeys. The reptiles also were more numerous, some of them of larger size than are now found in temperate regions. In the Lower Miocene formation, crocodiles, chelonians, and large batrachians, and in the Eocene deposits the same genera of reptiles, together with sea-snakes, bore testimony in like manner to the warm temperature of the seas, lakes, and rivers.

When we pass on to the uppermost member of the Cretaceous series, or the Maestricht chalk, as it is called, we find a similarly marked development of reptile life in regions where nothing analogous is now to be met with. Thus, in latitude 51° N., we encounter in St. Peter's Mount, Maestricht, the aquatic reptile called Mosasaurus, which was twenty-four feet in length. The same genus is largely represented in the American cretaceous rocks, from the various divisions of which Dr. Leidy has obtained more than twenty genera of reptiles, most of them extinct, but some, like the tortoises (*Trionyx* and *Emys*) and the crocodiles, of living types.* Several of the crocodiles of this age,

* Leidy, Cretaceous Reptiles of United States. Smithsonian contribution, 1865.

both in Europe and America, are procœlian, that is to say, they have the anterior portion of each vertebra concave, and the posterior part convex, in which respect they agree anatomically with the existing species, and are contrasted with all the older known genera of Mesozoic age. The reader will observe, on consulting Owen's table of the distribution of reptiles in past geological ages,* that of the five living orders, crocodiles, lizards, tortoises, snakes, and frogs, the two last-mentioned have not yet been traced as far back as the Secondary or Mesozoic periods, but the three first, the Crocodilia, Lacertia, and Chelonia, are met with in full strength in Cretaceous times, where they become associated with no less than three extinct orders, namely, Pterodactyls, Ichthyosaurs, and Plesiosaurs. Respecting the first of these, namely, the flying reptiles, it has been argued, that we have no right to assume that they required a hot climate, because they are so highly organised, and have so near an affinity to birds in structure, that they may have been warm-blooded, and as capable as birds of sustaining great cold. But the same argument will not apply to ichthyosaurs or to plesiosaurs, nor to the numerous chelonians which occur in the different divisions of the Cretaceous period, including the Wealden strata, in which large terrestrial saurians are so conspicuous.

How far extinct orders and genera may indicate temperature.—It has been objected, that in speculating on the habits and physiological constitution of plants and animals of an epoch so distant from our own as the Cretaceous, we enter a region of doubt and uncertainty, because even the Eocene species are distinct from the living ones, while the Cretaceous fossils differ as much from the Eocene as do the latter from living types. Dr. Fleming, therefore, when engaged in a controversy with Dean Conybeare, in 1830, as to the proofs of a hotter climate in the olden time, declared that the reasoning of his opponents was illogical, and their mode of dealing with the subject unfair. 'They were playing,' he said, 'with loaded dice;' for the large number of genera are now

* Owen, Palæontology, p. 321.

in tropical and sub-tropical zones, not because they could not live in colder regions, but simply because the land and sea in those zones are of wider extent, and support in equal areas a greater exuberance and variety of animal and vegetable forms. According, therefore, to the doctrine of chances, the majority of the genera of any past epoch, whether they be extinct or not, will have their nearest living analogues in hot countries. Many of them will be unrepresented in the colder parts of the globe, not because of their unsuitableness to the climate of such regions, but because of the comparative poverty of the fauna and flora of high latitudes. The fact, it is said, that the same genus has often species proper to the torrid, temperate, and frigid zones, is enough to demonstrate that it is on species alone that we can rely in questions of climate.*

The caution here enjoined is by no means to be disregarded, but our scepticism on this head may be carried too far. If three assemblages of existing species were submitted to a good naturalist, one of them coming from arctic, another from temperate, and a third from tropical latitudes, he would be able at once to assign the quarter from which each of the three groups had been obtained, even though he might never have seen any one of the *species* before. He would be guided partly by the presence of certain genera and orders, and partly by the absence or feeble representation of others in each group. It is by reasoning of this kind that we are able to arrive at conclusions respecting the temperature of periods when most of the genera and many even of the orders of plants and animals differ from those now living, and it must be remembered that when we study the modern Tertiary formations, in which a considerable proportion of the species are identical with living ones, we are able to infer from their associates what was the climate of many species and genera of animals and plants long since extinct. By this means, our data of comparison, when we are endeavouring to interpret the monuments of antecedent epochs, are greatly increased, since it is not merely to the living creation that we can appeal.

* Edinburgh New Phil. Jour., 1830.

Evidence of floating ice in the sea of the White Chalk in England.—The homogeneous character of the white chalk or upper portion of the great Cretaceous formation throughout a large part of Europe is now explained by the discovery that it is made up almost exclusively of the remains of the calcareous shells of Foraminifera, while the siliceous portions have been derived chiefly from plants called Diatoms. It was ascertained, when soundings were made for the Electric Telegraph, that calcareous mud of a similar character and origin is now forming over vast areas in the depths of the Atlantic. The general absence from the white chalk of sand, pebbles, drift-wood, and other signs of neighbouring land, is thus accounted for, but the occasional discovery of single and perfectly isolated stones, usually consisting of quartz and green schist, in the south-east of England, has naturally excited much surprise. In what manner could such stones have been carried far out into an open sea, so as to fall to the bottom without any admixture of other foreign matter? I formerly endeavoured to explain this enigma by referring to a fact observed by Mr. Darwin, namely, that stones of considerable size are occasionally entangled in the roots of floating trees, and transported to great distances in mid-ocean. One of them, as big as a man's head, was conveyed in this way for 600 miles to Keeling Island, a small ring of coral in the Indian Ocean. Seaweed also, called Kelp, *Fucus vesiculosus*, when uprooted, frequently bears along with it from shallow water pebbles and earth around which its roots have grown.

But, on reconsidering all the facts now observed, I agree with Mr. Godwin-Austen that there are some cases which we cannot account for without introducing the agency of ice. Thus, for example, in 1857, there was found at Purley, near Croydon, in the body of the white chalk, a group of stones, the largest of which consisted of syenite. This block had been broken up by the workmen before it was examined by any scientific observer, but the largest of the fragments was ascertained to be twelve inches in diameter in two directions, and to weigh upwards of twenty-four pounds. It was surrounded by granitic sand and pebbles of greenstone, and its dimensions rendered

the hypothesis of transportation by drift-timber inadmissible. There was, moreover, a total absence of carbonaceous matter, such as might have been looked for if a waterlogged tree had sunk on the spot. Mr. Godwin-Austen, therefore, has suggested that the pebbles and loose sand must have been frozen into coast-ice, and then floated out to sea, and the stones, he observes, mineralogically considered, present just such an assemblage as might now be found on a beach on the coast of Norway in lat. 60° N. As to the degree of cold required for the formation of such coast-ice, it may not, the same author remarks, have exceeded that occasionally experienced in our times on the eastern coast of England, from which ice has lifted and floated away far greater weights.*

Another example of a rounded block, weighing above thirteen pounds, had been previously noticed in the 'chalk with flints,' by Mr. Catt (now Mr. Willett), in a pit near Lewes. Attached to it was *Spondylus lineatus*, with serpulæ and some bryozoa. It had evidently been rolled before transportation, and before the serpulæ had fixed themselves on it. But no large angular blocks have as yet been met with in the white chalk, of such a size as to imply the agency of glaciers and icebergs.

Climate of the Oolitic and Triassic Periods.—When we enquire into the climatal state of the globe in times which preceded the Cretaceous, we find a very general agreement among zoologists and botanists as to the warmth of European latitudes in the Oolitic and Triassic eras. The vegetation of these periods consists chiefly of cycads, conifers, and ferns. Professor Heer remarks, that the tree which is most common in the Upper Trias in Switzerland has a near affinity to a living African species of Zamia,† and M. Adolphe Brongniart had long before expressed his opinion that the plants of the secondary periods favoured the hypothesis of a climate like that of the West Indies. The same genera, and, to some extent, the same species of ammonites and some other shells proper to oolitic strata in Europe, occur also in formations of the same age in India, as, for example, in Scinde and in Cutch, lat. 22° N. In a northerly direction the same formations

* Geol. Quart. Journ., vol. xiv., 1858. † Heer, Urwelt der Schweiz, p. 51.

reach within 13½ degrees of the pole, as was shown by the fossil specimens brought home by Sir Leopold McClintock. Among these the Rev. Samuel Haughton recognises a species closely allied to the *Ammonites concavus* of the Lower Oolite which was found at Prince Patrick's Island, lat. 77° 10′ N. In Cook's Inlet also, lat. 60° N., several ammonites of jurassic types, if not species, were obtained, and *Belemnites paxillosus*, a British liassic fossil. But what is far more remarkable, remains of a large ichthyosaurus of liassic type were brought from an island in lat. 77° 16′ by Sir Edward Belcher. They have been described and figured by Professor Owen, and as some of the vertebræ were 2½ inches in diameter, the animal must have been of considerable size.* More recently, in 1866, the remains of ichthyosaurians were found by the naturalists of the Swedish expedition, in strata of jurassic age in Spitzbergen in the still more northern latitude of 78° 30′.

Abundance and variety of reptiles implies warm climate.— The reptiles of the Oolite and Lias, and of the still older Trias, are so numerous and diversified in form that the period of the secondary or mesozoic rocks has been called the age of reptiles. The number of marine genera alone of this class exceeds fifty, while that of the fresh-water and terrestrial species, including those of aërial habits, is almost as great as that of the tribes which peopled the sea. Some of these were more highly organised than any animals of the same class now living, as the Belodon, for example, of the Upper Trias, a saurian about the size of the largest living crocodile, but which belonged to the extinct order of Dinosaurians. Hermann von Meyer ascertained, in 1865, that it possessed breathing apertures or spout-holes like the whale, so that we might imagine it to have been capable of sustaining a cold climate were it not associated with many reptiles of lower grade, as well as with shells, corals, and plants which bespeak a high temperature. On the whole, no less than eighty reptiles have been described by Hermann von Meyer, all derived from the Trias of Germany alone. They belong entirely to extinct orders, but all of which, according to

* Last of Arctic Voyages.

Owen,* display affinities more or less decided to living families of the same class, while in the overlying liassic and oolitic groups we find representatives of the crocodilian and chelonian orders which still exist, together with the four extinct orders the Pterosaurs, Ichthyosaurs, Plesiosaurs, and Dinosaurs. These exhibit various grades of organisation, and the analogy of the living creation is strongly in favour of their having flourished in a climate in which the heat was considerable during part of the year, and the winter brief and never severe.

Thus, in some of the temperate regions of the southern hemisphere at present, where the winters are long and the summers cool, there is an entire absence of reptile life—in Tierra del Fuego, for example, and in the woody region immediately north of the Straits of Magellan (between latitudes 52° and 56° S.), and in the Falkland Islands. Not even a snake, lizard, or frog, is met with; although in these same countries we find the guanaco (a kind of llama), a deer, the puma, a large species of fox, many small rodentia, and, in the neighbouring sea, the seal, together with the porpoise, whale, and other cetacea.

In the arctic regions, at present, reptiles are small, and sometimes wholly wanting, where birds, large land quadrupeds, and cetacea abound. We meet with bears, wolves, foxes, musk-oxen, and deer, walruses, seals, whales, and narwhals, in regions of ice and snow, where the smallest snakes, efts, and frogs are rarely, if ever, seen.

The power of reptiles to bury themselves in the earth, and to hybernate in a state of torpidity, enables them to exist in extra-tropical regions, but not where the winter's cold is excessive or of long duration.

Absence of mammalia does not explain the wide range of reptiles.—In none of the secondary rocks, as before stated, have any mammalia clearly referable to the placental division been found, whether of terrestrial or aquatic genera. Their absence may partly account for the extraordinary number of genera, species, and individuals of the reptile class. For the

* See a table of geological distribution of reptiles in Owen's Palæontology, p. 321, 2nd edit., 1861.

reptiles enjoyed in those periods a monopoly of a large portion of the habitable surface which they are now obliged to share with the more powerful mammalia. In the struggle for existence they had only to compete with marsupials of very diminutive size, and, so far as we know, there were few contemporary birds, so that to a great extent the reptiles performed the functions in the air, on the land, and in the water, which the two highest classes of vertebrata now discharge. But granting that the predominance of reptiles is checked in our days by the important part played by the more highly organised vertebrata, we can by no means attribute the present scarcity of saurians (crocodiles and iguanas), lizards, tortoises, snakes, and the larger batrachians in high latitudes, as contrasted with their abundance in secondary periods, to the progress which the animate world has made in that great interval towards a more highly organised state. All the above-mentioned orders of reptiles are able to maintain their ground at present against the ape, elephant, rhinoceros, tiger, deer, and other mammalia, large and small, in all zones where they are favoured by sufficient heat. If they are absolutely wanting in polar regions it is evidently not the competition of the bears, musk-buffalos, walruses, and whales which sets a limit to their range in that direction, but the power of frost.

There is no area in the globe at present, between the parallels of 40° and 60°, where a climate exists like that which we may suppose to have prevailed when the triassic and oolitic rocks were formed. But perhaps the nearest approach to it may be found in the Galapagos Archipelago (situated nearly 600 miles west of the coast of Peru), which is of volcanic origin and contains ten principal islands, some of them from 3,000 to 4,000 feet high, and one of them, Albemarle Island, 75 miles long. Placed under the equator, the heat is greater than in temperate latitudes, but it is moderated by the surrounding ocean, and by a current of cold water which flows from Patagonia northwards along the west coast of South America. This archipelago has been called the land of reptiles, from the extraordinary number of large tortoises, together with lizards and snakes, which it supports. Among the lizards are two species of a peculiar

genus, called Amblyrhyncus, one of them terrestrial and the other aquatic. The latter is marine, laying its eggs in the seaweed under water; it affords the only living example, with the exception of some sea-snakes, of a reptile proper to the ocean, and it serves to show that the existence of seals and cetacea, which abound in the Pacific, form no bar to the coexistence of aquatic reptiles in the same region. The number of individual tortoises and other reptiles could not possibly be so great in these islands, were it not for the absence of mammalia, for a single indigenous species of mouse was the only representative of this class when Mr. Darwin visited the archipelago in the Beagle in 1835. Even this rodent seems to have been confined to Chatham Island, and may possibly be a variety of a South American form, introduced by the buccaneers. In James Island a rat belonging to the old-world division, no doubt brought by some ship, had been naturalised. All the islands were uninhabited by man until about 1832, when the first small colony was founded. In the fauna of the Galapagos islands we have therefore a state of things very analogous to that of the secondary periods before alluded to.

The rich marine fauna of the St. Cassian beds in the Austrian Alps, and of the district of d'Esino in Lombardy, so well illustrated by Stoppani, affords evidence, through its gigantic Ammonites and Orthocerata, and by the large size of the Gasteropoda and Lamellibranchiata, that in the east of Europe the seas enjoyed a warm climate, at the same time that in the west the triassic reptiles before mentioned were swarming on the land and in the rivers and estuaries. This St. Cassian fauna is known to extend as far north as lat. 55°, and has been traced as far south in India as the Himalaya mountains in lat. 30°, showing that the elevated temperature alluded to was of wide geographical extent.

Triassic conglomerate.—The great size of some fragments of rock in the New Red Sandstone, probably of Triassic age, in Devonshire, has led Mr. Godwin-Austen to refer their transport to ice-action; but this opinion has been controverted by Mr. Pengelly,* who has shown that such masses

* See his Paper on the Red Sandstone Conglomerates of Devonshire, part ii.

may not have travelled far, and are such as might have been moved by breakers beating against a wasting cliff.

Permian fossils.—Between the Triassic and Permian rocks there is a break which doubtless implies a great lapse of time, of which the records are wanting, in that part of the globe as yet best known to the geologist. It constitutes the line of division between the primary and secondary, or between the Palæozoic and Mesozoic formations. The Permian rocks have been traced as far north as Petschora-land in Russia between lat. 65° and 70° N. They occur largely in Germany and England; and in North America have been traced as far south as Kansas and Nebraska, lat. 44° N.

Amongst the Permian shells we find the genera Nautilus and Orthoceras, and these are sometimes accompanied by large reptiles of a family called Thecodonts, which combine in their structure many characters of the living crocodiles and lacertians. They are most nearly allied to the Varanian Monitors, which now inhabit tropical countries. The fossil plants of the Permian formation are very like those of the antecedent carboniferous strata, of which I shall presently speak, and indicate the prevalence of a warm and moist climate throughout a great part of the northern hemisphere.

Supposed signs of ice-action in the Permian Period.—Professor Ramsay, in an able memoir published in 1855, gave an account of observations made by him on a brecciated conglomerate of Permian age in Shropshire, Worcestershire, and other parts of England, which had led him to infer the action of floating ice in the seas of that remote period. His arguments are founded on the following facts:—the fragments of various rocks imbedded in these breccias are often angular, and of large size, some of them weighing more than half a ton; they are very often flat-sided, and have one or more of their surfaces polished and striated. They are generally enveloped in a red unstratified marl, in which they lie confusedly, like stones in boulder-drift. In some cases it can be demonstrated that the nearest points from which these stones could possibly have been conveyed are the mountains of Wales, more than twenty, thirty, or even

fifty miles distant; and it is inferred that the only way in which they could have retained their angular shape, after being transported so far from their original position, is by being carried by floating ice. Some of the specimens also taken by the Professor out of the breccia, and now exhibited in London, in the Jermyn Street Museum, have their surfaces rubbed, flattened, and furrowed, like stones subjected to glacial action. One of the most characteristic of these specimens was obtained from a spot about six miles south-east of Bridgenorth, near the village of Enville in Worcestershire. The fragment is six inches in its longest diameter, consists of hard dark Cambrian grit, with a smoothed surface, exhibiting parallel sets of striæ in more than one direction,* a newer set crossing the older one. I am fully satisfied that such fragments have been taken out of the breccia, and the explanation offered by Professor Ramsay appears to me the most natural, indeed the only one in the present state of science which can be suggested. That glaciers should have reached the sea in lat. 53°, in England, cannot surprise us when we see them coming down at present to within 500 feet of the sea in New Zealand, in lat. 44°, or much nearer the equator; and it has been already stated (p. 210) that tree-ferns and even palms now flourish in New Zealand, in the immediate neighbourhood of these glaciers. It should also be borne in mind, that there is a great dearth of fossil remains in the Permian conglomerates of Central England; and we know not by what plants or animals the lands and seas were inhabited at the time of their accumulation, and, consequently, we are ignorant, so far as we depend on organic evidence, of the nature of the climate which prevailed in that part of the Permian era, when the stones which have apparently been glaciated were carried to their present sites. Professor Suess, who has studied the Permian conglomerate or Rothliegende in various parts of the Alps, says that it shows signs of great denudation of pre-existing land by the large quantity of quartz pebbles which it contains, but hitherto no signs of ice-borne rocks have there been met

* Ramsay, Quart. Geol. Journ., vol. ii. 1855.

with. The Alpine localities, however, are about 5° south of those alluded to in Great Britain.

Climate of Carboniferous Period—fossil plants.—If we next consider the climate of the Carboniferous period, we shall find that botanists have considerably modified the ideas which they originally entertained respecting the tropical temperature supposed to be indicated by the fossil plants of that era. The fruit called Trigonocarpon, occurring in such profusion in the coal measures, was at first referred to the palm tribe, till the discovery of more perfect specimens enabled Dr. Hooker to decide that it was not a palm, but more probably belonged to a taxoid conifer, somewhat like the Chinese Salisburia. The structure of the coniferous wood preserved in these strata exhibits some points of analogy with the Araucariæ of Chili, Brazil, New Holland, and Norfolk Island.

M. Adolphe Brongniart has observed that the great numerical preponderance of ferns over other forms of vegetation in the Carboniferous era gives us ground to conclude that the climate was warm and moist. It must be confessed that this reasoning loses some of its force when we consider that the ancient flora is almost entirely destitute of those flowering plants which now constitute three-fourths of the living vegetation. The ferns of the Coal period had fewer rivals to compete with, and more space in which to develop themselves freely; still, the fact that many of them belong to arborescent genera, such as Caulopteris, Zippea, Sphalmopteris, and Stemmatopteris, would incline us to think, according to the analogy of the living creation, that the climate was warm, moist, and equable, for tree-ferns are now most abundant in islands of the tropical ocean, although some species extend in New Zealand, as before stated, as far towards the antarctic regions as the 46th degree of south latitude. A warm climate seems also implied by the other vascular cryptogams which, together with the ferns, form nineteen-twentieths of the carboniferous flora. They belong to families allied to ferns, such for example as the Sigillariæ, Lepidodendra, and Calamites, and most of them attained a vastly greater size, growing even to the height of forest trees, and had a more complex structure, than any of their modern

representatives. Their stems had also a lax tissue and, like living cryptogams of the same families, they must have derived the greater part of the water which entered into their composition, as well as their carbon, by their leaves from the air. They probably flourished, therefore, in an atmosphere highly charged with aqueous vapour, and such an atmosphere must have been warm. Yet we must not suppose the heat to have been tropical, for hot sunshine, by promoting the decomposition of vegetable matter, is adverse to the formation of coal as it is to that of peat.

As to the geographical range in the northern hemisphere of this ancient flora, it is already ascertained that it extends from Alabama in the United States in lat. 30° to the arctic regions, while it has been traced in Europe from central Spain in lat. 38° to Scotland in lat. 56°. In the arctic regions it was first observed in Melville Island, in lat. 75°, during Capt. Parry's expedition. The plants then collected were examined by the late Dr. Lindley, who recognised them as true fossils of the ancient coal.* The original collection has unfortunately been lost, but among other fossils since brought from the same island by Sir Leopold McClintock, Heer has recognised ferns of the genus *Schizopteris*, a form characteristic of the ancient coal. Middendorf found *Calamites cannæformis* in a very high latitude near the mouths of the Lena. Von Buch has described strata of the Coal period containing characteristic marine fossils in Bear Island, lat. 74° 36′ N., midway between Spitzbergen and the North Cape, in about the same parallel as Melville Island; and from associated rocks of the same age and in the same locality Heer has received as many as fifteen species of plants well known as occurring in different stages of the European Carboniferous formation.†

After what was said at p. 201 of the spread of the Miocene flora over the arctic regions, and its near approach to the North Pole, the reader will feel no surprise at finding that in times long antecedent there was an equally vigorous vegetation in the same latitudes. Moreover, the coal plants

* Penny Cyclopædia, art. Coal Plants.

† Student's Elements, p. 424.

were of different genera, and some few of them perhaps of different orders, from any now existing, and they may therefore have been endowed with a constitution enabling them to accommodate themselves to a long polar night.

We know, by experiment, that plants which are natives of the tropics can dispense more easily with the bright light of those countries than with the heat of the same. Few palms can live in our temperate latitudes without protection from the cold; but when placed in hot-houses they grow luxuriantly, even under a cloudy sky, and where much light is intercepted by the glass and framework. At St. Petersburg, in lat. 60° N., many tropical plants have been successfully cultivated in hot-houses, although there they must exchange the perpetual equinox of their native regions for days and nights which are alternately protracted to nineteen hours and shortened to five. How much farther towards the pole even the existing species might continue to live, provided a due quantity of heat and moisture were supplied, has not yet been determined; but St. Petersburg is probably not the utmost limit, and we should expect that in lat. 65° at least, where they would never remain twenty-four hours without enjoying the sun's light, they might still exist.

Supposed excess of carbonic acid in the air.—That the air was charged with an excess of carbonic acid in the Coal period has long been a favourite theory with many geologists, who have attributed partly to that cause an exuberant growth of plants. It has been said that there is ten times more carbon locked up in a solid form in the ancient coal-measures than all that is now contained in the atmosphere; but granting the truth of this estimate, which is probably far below the mark, the soundness of the inference has always appeared to me most questionable. The atmosphere now receives large supplies of carbonic acid by gaseous emanations from the interior of the earth, which are most copiously given out in volcanic regions, and especially by volcanos during eruptions. Carburetted hydrogen also escapes from beds of coal and lignite and other fossiliferous strata in which organic matter is decomposing; the same gas evidently rising from great depths is also evolved from rents in the granitic and other crystalline

rocks in which there are no organic remains. But it does not follow that the air is becoming more and more loaded with carbonic acid, for there are causes in action which prevent such a change in the constitution of the atmosphere. Wherever drift-timber is buried in the delta of a river, sea, or lake, or wherever peat is forming, we behold the process by which carbon is first extracted by the powers of vegetation from the atmosphere, and then locked up permanently, or for ages, in the earth's crust. As to the volume of carbonaceous matter which may thus be accumulated, it is a mere question of the time for which certain species of plants, together with the conditions fit for making peat and for burying drift-timber, may endure.*

Some botanists are of opinion that the Sigillaria in the Carboniferous period played the same part which is now performed by the Sphagnum in Europe, both of them tending to relieve the atmosphere of part of the carbonic acid which is incessantly evolved from the interior of the earth. Mr. Darwin attributes the small quantity of peat formed in some regions of South America which are exceedingly damp to the absence of species of plants peculiarly fitted for its production. The abundance of coal, therefore, in certain districts may have arisen from the peculiarity of the vegetation, and of a climate which prevented decomposition, rather than from a peculiarity in the atmosphere which enveloped the globe in the Carboniferous period. In the Runn of Kutch there is a great annual deposit of salt caused by the evaporation of sea-water; but this arises from geographical causes wholly unconnected with the chemical condition of the ocean, which is not supposed to contain in that part of India more than its average proportion of chloride of sodium. The quantity of rock salt stored up in the Runn of Kutch, if that large district should be slowly subsiding, may in time exceed in amount all the brine now held in solution by the ocean, but if so, future geologists will have no right to conclude that during such an accumulation of chloride of sodium the waters of the sea generally were more salt than they usually are. Nay, it would be even safer to conclude that during the period when

* See below, Chap. XVII.

so much rock salt was forming, the waters of the ocean would contain less than their average quantity of brine.

Fossil shells and corals of the Carboniferous period.—If we now turn from the flora to the fauna of the Carboniferous period, we find among the invertebrate animals many large chambered shells of Cephalopoda, such as Nautilus, Orthoceras, and others, as well as stone-lilies or encrinites, and corals, all of which families flourished in those secondary periods, when, for reasons already explained, a warm climate is supposed to have prevailed. It may indeed be objected, in regard to the corals, that they all belong to types only met with in the primary or palæozoic rocks; that is to say, to the orders *Zoantharia rugosa* and *Z. tuberculata* of Milne-Edwards, which with one exception became extinct after the Permian era; but it must be remembered that these Palæozoic cup and star corals of the older or quadripartite type have such a range, from tropical to northern regions, that we must either suppose them to have had greater powers of adaptation to differences of climate, or that the seas of high and low latitudes had a more equable temperature than they have now.

Reptiles of Coal.—No representatives of the Vertebrata have been found in the Carboniferous formation except reptiles and fish. The species of the former class are confined to two extinct orders, *Ganocephala* and *Labyrinthodontia*, which are represented by thirteen genera in the coal-measures of England and Ireland. Both of these depart widely from living types, but approach most nearly to the tailed batrachians of our time, to which the salamanders and certain perennibranchiate batrachians belong. All these are members of the sub-class Amphibia, which are regarded by many zoologists as intermediate between true reptiles and fish. Their nearest living allies are only found at present in the northern hemisphere, where they have, according to Mr. Günther, a wide range from north to south, in America, as well as Europe and Asia. They are most numerously represented in genera, species, and individuals in the Southern United States, and on the table-land of Mexico. In Guatemala we find that in lat. 15° N. they have already become scarce, being reduced to one or two

forms. As to their extension in the opposite direction, some small species occur in the Canadian lakes; one of these, of the Menobranchus family, *Giredon hiemalis*, having been observed as far north as Lake Superior, in a place where the water was frozen over an inch thick every night for three months.* Such a geographical distribution is confirmatory of the conclusions as to climate to which we have been led by the plants of the Carboniferous era, as the tailed batrachians attain their fullest development between the 20th and 40th degrees of latitude, or in a warm zone free from intense heat or cold.

Devonian Period.—In the antecedent Devonian period there are no reptiles, not even any of the order Amphibia. There are abundance of Ganoid fish, which have their nearest living analogues in the rivers of Northern Africa, for they are closely related to the African Polypterus, of which several species are found in the Nile, and others in the rivers of Senegal. The associated Placoid fish belong also to a family found chiefly in equatorial regions, though having a wide range into cooler latitudes. The Devonian, or Old Red crustaceans such as Pterygotus and Eurypterus, attain some of them a length of five or six feet, and are therefore most comparable, in size at least, to crustaceans such as the King Crab, now living in Japan and America, and in regions still nearer the equator. The mollusca and corals resemble generically those of the Carboniferous period. The Devonian flora is chiefly known to us through the labours of American geologists in the State of New York, and in Canada as far north as lat. 49°. More than sixty American species are enumerated by Dr. Dawson from that continent, and they comprise so large a portion of the carboniferous genera, including tree-ferns, as to point to a similarity of climate. The same may be said of the European plants of corresponding age, so far as they are known.

Supposed signs of ice-action in the Old Red Sandstone, or Devonian Period.—The Rev. J. G. Cumming, in 1848, in his History of the Isle of Man, compared the conglomerate of the Old Red Sandstone to 'a consolidated ancient boulder clay;'

* Dr. Samuel Kneeland, Proceed. Boston Soc. Nat. Hist., vol. vi. p. 152.

and more recently (1866), Professor Ramsay has pointed out that the conglomerate of the same age seen at Kirkby-Lonsdale, and Sedbergh, in Westmoreland and Yorkshire, contains stones and blocks distinctly scratched, and with longitudinal and cross striations, like the markings produced by glacial action. I have myself examined this rock, and have seen blocks taken from it which exhibit such markings, some of them undistinguishable from those which I have observed on blocks taken from beneath a glacier. But Professor Ramsay has himself adverted to the fact, that the conglomerate above alluded to has been subjected to violent movements in different directions, and to great pressure after it was buried under thousands of feet of carboniferous strata. In consequence of these movements, some markings have been produced within the body of the rock itself, one pebble having occasionally been squeezed and forced against another, so as to indent it. Many of the pebbles also, and stones two feet and more in diameter, have acquired that polish which is called slickenside; and the same may be seen in various parts of the marly matrix. We must not forget that the district in question is exactly in the line of a great system or succession of faults, so that here there has been an unusual repetition of movement and dislocation of rock, which makes it difficult to decide in many cases to what kind of mechanical action the effects alluded to have been due. More evidence, I think, must be obtained before we can feel perfectly convinced that the markings in question have had a glacial origin.

Climate of the Silurian Period.—When we enquire into the climate of the Silurian and still older formations, we find ourselves deprived of some important classes of evidence on which we have relied when considering the organic remains of the formations of later date. Reptiles fail us entirely, as in the Devonian rocks; fish are wanting, except a few remains in the Upper Silurian; of plants there are none, save a few doubtful fucoids and a few cryptogamic sporangia in the Upper Ludlow: we must therefore be content to form our opinion as to the state of the climate from those genera of invertebrate animals of which there is a great profusion,

but which usually in the primary strata depart widely from tertiary and living types. Of the probable bearing on climate of the large crustaceans of the genera Eurypterus and Pterygotus I have already spoken when treating of the Devonian beds, and we find them equally well represented by other species of the same genera in the higher beds of the underlying Silurian. The numerous trilobites, large chambered cephalopods, the corals, and the crinoids are also so like those of the newer members of the Palæozoic series as to make us incline to believe that a similar climate prevailed in the northern hemisphere, and a somewhat uniform temperature from equatorial to very high latitudes. In speculating, however, on this subject, we must not forget that much light has recently been thrown by deep-sea dredging on the uniformity of temperature which may prevail in the ocean from high to low latitudes, at depths now known to be inhabited, though formerly supposed to be below the zero of animal life.

Concluding remarks on Climate.—The result then of our examination in this and in the preceding chapter of the organic and inorganic evidence as to the state of the climate of former geological periods is in favour of the opinion that the heat was generally in excess of what it now is. There have been oscillations of temperature, and at least one period of excessive cold of comparatively modern date. In the greater part of the Miocene and preceding Eocene epochs the fauna and flora of Central Europe were subtropical, and a vegetation resembling that now seen in Northern Europe extended into the arctic regions as far as they have yet been explored, and probably reached the pole itself. In the Secondary or Mesozoic ages, the predominance of reptile life, and the general character of the fossil types of that great class of vertebrata, indicate a warm climate and an absence of frost between the 40th parallel of latitude and the pole, a large ichthyosaurus having been found in lat. 77° 16′ N. The great development also of the tetrabranchiate and dibranchiate cephalopoda, with the general character of the mollusca and corals, as well as of the plants, is in perfect accordance with the

inferences deduced from the associated fossil reptiles. If we then carry back our retrospect to the primary or Palæozoic ages, we find an assemblage of plants which imply that a warm, humid, and equable climate extended in the Carboniferous period uninterruptedly from the 30th parallel of latitude to within a few degrees of the pole, or to northern regions where at present the severe winter's frost, and the almost universal covering of snow lasting for many months, preclude the existence of a luxuriant vegetation. A still older flora, the Devonian, so far as we have yet traced its geographical extension, leads to similar inferences, and the invetebrate fauna of the Devonian, Silurian, and Cambrian rocks has such a generic resemblance to that of the Carboniferous, Permian, and Triassic periods as to imply that a similarity of conditions in regard to temperature prevailed throughout the whole of these six periods.

As to the supposed indications of ice-action in the Miocene and Eocene and the still remoter Permian periods, the reader must not forget the caution already given (p. 210), that should we meet with erratic blocks of the largest size, having one or more glaciated surfaces, included in sedimentary strata between latitudes 40° and 50°, these blocks may have been carried to their present destination without the aid of glacial conditions more intense than those now supplied by the present state both of the northern and southern hemispheres. We learn from Captain Evans's ice-chart * that in January 1850 icebergs reached even to the Cape of Good Hope, in lat. 35° S.; and we shall see in Chapter XVI. that large erratic blocks have been seen imbedded in icebergs floating far from land in the southern seas.

* Admiralty Charts, 1865, No. 1241. See also p. 249.

CHAPTER XII.

VICISSITUDES IN CLIMATE CAUSED BY GEOGRAPHICAL CHANGES.

ON THE CAUSES OF VICISSITUDES IN CLIMATE—ON THE PRESENT DIFFUSION OF HEAT OVER THE GLOBE—MEAN ANNUAL ISOTHERMAL LINES—DEPENDENCE OF THE MEAN TEMPERATURE ON THE RELATIVE POSITION OF LAND AND SEA—CLIMATE OF SOUTH GEORGIA AND TIERRA DEL FUEGO—COLD OF THE ANTARCTIC REGION—OPEN SEA NEAR THE NORTH POLE—EFFECT OF CURRENTS IN EQUALISING THE TEMPERATURE OF HIGH AND LOW LATITUDES—THE PRESENT PROPORTION OF POLAR LAND ABNORMAL—SUCCESSION OF GEOGRAPHICAL CHANGES REVEALED TO US BY GEOLOGY—MAP SHOWING THE AMOUNT OF EUROPEAN LAND WHICH HAS BEEN UNDER WATER SINCE THE COMMENCEMENT OF THE EOCENE PERIOD—ANTIQUITY OF THE EXISTING CONTINENTS—CHANGES IN GEOGRAPHY WHICH PRECEDED THE TERTIARY EPOCH—MAP SHOWING THE UNEQUAL DISTRIBUTION OF LAND AND WATER ON THE GLOBE—FORMER GEOGRAPHICAL CHANGES WHICH MAY HAVE CAUSED THE FLUCTUATIONS IN CLIMATE REVEALED TO US BY GEOLOGY—IDEAL MAP WITH THE EXCESS OF LAND REMOVED FROM POLAR TO TROPICAL REGIONS—GREAT DEPTH OF THE SEA AS COMPARED TO THE MEAN HEIGHT OF THE LAND, AND ITS CONNECTION WITH THE SLOWNESS OF CLIMATAL CHANGES.

Causes of vicissitudes in climate.—As our retrospective survey of the fossiliferous rocks of successive periods, given in the last two chapters, has led us to infer that the earth's surface has experienced great changes of climate since it has been inhabited by living beings, we have next to enquire how such vicissitudes can be reconciled with the existing order of nature. The earlier speculators in geology availed themselves of this, as of every obscure problem, to confirm their views concerning a period when the planet was in a nascent or half-formed state, or when the laws of the animate and inanimate world differed essentially from those now established; and in this, as in many other cases, they succeeded, to no small extent, in diverting attention from that class of facts which, if fully understood, might have led the way to an explanation of the phenomena. At first it was imagined that the earth's axis had been for ages perpendicular to the

plane of the ecliptic, so that there was a perpetual equinox, and uniformity of seasons throughout the year; that the planet enjoyed this 'paradisiacal' state until the era of the great flood; but in that catastrophe, whether by the shock of a comet, or some other convulsion, it lost its equipoise, and hence the obliquity of its axis, and with that the varied seasons of the temperate zone, and the long nights and days of the polar circles.

When the progress of astronomical science had exploded this theory, it was assumed, that the earth at its creation was in a state of igneous fluidity, and that, ever since that era, it had been cooling down, contracting its dimensions, and acquiring a solid crust. It was also taken for granted that this original crust was the same as that which we are now studying, and which contains the monuments of a long series of revolutions in the animate world. This notion, however arbitrary, was well calculated for lasting popularity, because it referred the mind directly to the beginning of things, and required no support from any ulterior hypothesis. But the progress of geological investigation gradually dissipated the idea, at first universally entertained, that the granite or crystalline foundations of the earth's crust were of older date than all the fossiliferous strata. It has now been demonstrated that this opinion is so far from the truth that it is difficult to point to a single mass of volcanic or plutonic rock which is more ancient than the oldest known organic remains. Such being the case, the question of original fluidity, although a matter of legitimate speculation to the physicist, is one with which the geologist is but little concerned. It may relate to a state of things which preceded our earliest records by a lapse of ages many times greater than the entire series of geological epochs with which we are acquainted.

If, instead of indulging in conjectures as to the state of the planet at the era of its creation, we fix our thoughts steadily on the connection at present existing between climate and the distribution of land and sea, and then consider what influence former fluctuations in the physical geography of the globe must have had on superficial temperature, we may

make a near approximation to a true theory. But the effect of former variations in the heat and cold of the different seasons in the year, caused by the precession of the equinoxes, combined with the revolution of the apsides, and still more by variations in the excentricity of the earth's orbit, will have to be taken into account, as subsidiary to the more dominant influence of geographical conditions. Should doubts and obscurities still remain, they should be ascribed to our limited acquaintance with the laws of Nature, not to revolutions in her economy. They should stimulate us to farther research, not tempt us to indulge our fancies respecting imaginary changes of internal temperature, or the unsettled state of the surface of a planet before it was prepared for the habitation of living beings.

Diffusion of heat over the globe.—In considering the laws which regulate the diffusion of heat over the globe, we must be careful, as Humboldt well remarks, not to regard the climate of Europe as a type of the temperature which all countries placed under the same latitude enjoy. The physical sciences, observes this philosopher, always bear the impress of the places where they began to be cultivated; and as, in geology, an attempt was at first made to liken all the volcanic phenomena to those of Italy, so in meteorology, a small part of the old world, the centre of the primitive civilisation of Europe, was for a long time considered a type to which the climate of all corresponding latitudes might be referred. But this region, constituting only one-seventh of the whole globe, proved eventually to be the exception to the general rule. For the same reason, we may warn the geologist to be on his guard, and not hastily to assume that the temperature of the earth in the present era is a type of that which most usually obtains, since he contemplates far mightier alterations in the position of land and sea, at different epochs, than those which now cause the climate of Europe to differ from that of other countries in the same parallels of latitude.

It is now well ascertained that zones of equal warmth, both in the atmosphere and in the waters of the ocean, are neither

parallel to the equator nor to each other.* It is also known that the *mean* annual temperature may be the same in two places which enjoy very different climates, for the seasons may be nearly uniform, or violently contrasted, so that the lines of equal winter temperature do not coincide with those of equal annual heat or isothermal lines. The deviations of all these lines from the same parallel of latitude are determined by a multitude of circumstances, among the principal of which are the position, direction, and elevation of the continents and islands, the position and depths of the sea, and the direction of winds and currents.

On comparing the two continents of Europe and America, it is found that places in the same latitude have sometimes a mean difference of temperature amounting to 11°, or even in a few cases to 17° Fahr.; and some places on the two continents, which have the same mean temperature, differ from 7° to 17° in latitude. Thus, Cumberland House, in North America (see fig. 9, p. 240), having the same latitude (54° N.) as the city of York in England, stands on the isothermal line of 32°, which we have to seek in Europe at the North Cape, in lat. 71°, but its summer heat exceeds that of Brussels or Paris.† The principal cause, says Humboldt, of the greater intensity of cold in corresponding latitudes of North America, as contrasted with Europe, is the connection of America with the polar circle, by a large tract of land, some of which is from three to five thousand feet in height; and, on the other hand, the separation of Europe from the arctic circle by an ocean. The ocean has a tendency to preserve

* We are indebted to Alex. von Humboldt for having first collected together the scattered data on which he founded an approximation to a true theory of the distribution of heat over the globe. Many of these data were derived from the author's own observations, and many from the works of M. Pierre Prévost, of Geneva, on the radiation of heat, and from other writers.—See Humboldt on Isothermal Lines, Mémoires d'Arcueil, tom. iii. translated in the Edin. Phil. Journ. vol. iii. July 1820.

The map of Isothermal Lines, published by Humboldt and Dove in 1848 (re-edited by Dove in 1853, from which fig. 9 is extracted), supplies a large body of well-established data for such investigations, of which Mr. Hopkins availed himself in an able essay 'On the Causes which may have produced Changes in the Earth's Superficial Temperature.'—Q. Journ. Geol. Soc. 1852, p. 56.

† Sir J. Richardson's Appendix to Sir G. Bach's Journal, 1843–1845, p. 478.

everywhere a mean temperature, which it communicates to the contiguous land, so that it tempers the climate, moderating alike an excess of heat or cold. The elevated land, on the other hand, rising to the colder regions of the atmosphere, becomes a great reservoir of ice and snow, arrests, condenses, and congeals vapour, and communicates its cold to the adjoining country. For this reason, among others, Greenland, forming part of a continent which stretches northward to the 82nd degree of latitude, experiences under the 60th parallel a more rigorous climate than Lapland under the 72nd parallel.

But if land be situated between the 45th parallel and the equator, it produces, unless it be of great height, exactly the opposite effect; for it then warms the tracts of land or sea that intervene between it and the polar circle. For the surface being in this case exposed to the vertical or steeply sloping rays of the sun, absorbs a large quantity of heat, and raises the temperature of the atmosphere which is in contact with it. For this reason, the western parts of the old continent derive warmth from Africa, 'which, like an immense furnace, distributes its heat to Arabia, to Turkey in Asia, and to Europe.' * The north-eastern extremity of Asia, on the contrary, experiences in the same latitude extreme cold; for it has the land of Siberia on the north between the 65th and 70th parallel, while to the south it is separated from the equator by the Pacific Ocean.

A large proportion of the sun's heat is employed in the tropics in changing water from the liquid to the gaseous state, being thus absorbed without affecting the thermometer. The moist aërial currents therefore, which take their rise over the ocean and damp regions of equatorial land, carry a large quantity of latent heat to more northern latitudes, which is set free as the wind cools and precipitates its vapour in the form of water or snow. 'Thus aqueous vapour,' says Herschel, 'becomes an agent in the transfer of heat, in its latent state, from one part of the globe or from one region of the atmosphere to another.'† The upper trade winds (or anti-trades), which pass freely above the peaks of all but the

* Malte-Brun, Phys. Geol. book xvii. † Herschel, Meteorology, 1862, art. 51.

highest mountains, are able to pursue an almost unbroken course over tropical and subtropical latitudes, until they come to those more northern regions where the act of condensation releases probably as much as three-fourths of their heat. The surface of the land is sometimes raised to a temperature of 159° F. in South Africa, and perhaps even higher in Australia (see p. 283), while the surface of the ocean is rarely heated over 80° F. The effect therefore of land at the equator will be to cause the hot air to rise with much greater velocity than it would off the ocean, and to carry rapidly, from localities moist enough to provide it with aqueous vapour, a large volume of heat to more northern latitudes. We must not forget also that, besides this action at great heights of what has been called the upper trade winds, aërial currents, such as the well-known Scirocco in Italy and the Föhn in Switzerland, blowing from tropical to temperate regions at a lower level, occasionally cause the rapid melting of the snows of the Apennines and Alps.

In July 1841, according to M. Denzler, the Föhn blew tempestuously at Algiers, and, crossing the Mediterranean, in six hours reached Marseilles, and in five hours more it was at Geneva and the Valais, throwing down a large extent of forest in the latter district, while in the cantons of Zurich and the Grisons it suddenly turned the leaves of many trees from green to yellow. In a few hours new-mown hay was dried and ready for the haystack. The snow-line of the Alps was seen by M. Irscher the astronomer, from his observatory at Neufchâtel, by aid of the telescope, to rise sensibly every day while the Föhn was blowing. Its influence is by no means confined to the summer season, for in the winter of 1852 it visited Zurich at Christmas, and in a few days all the surrounding country was stripped of its snow, even in the shadiest places and on the crests of high ridges; and Escher von der Linth has pointed out that in proportion to the number of days that this dry wind blows, the Alpine glaciers advance or retreat in particular years.

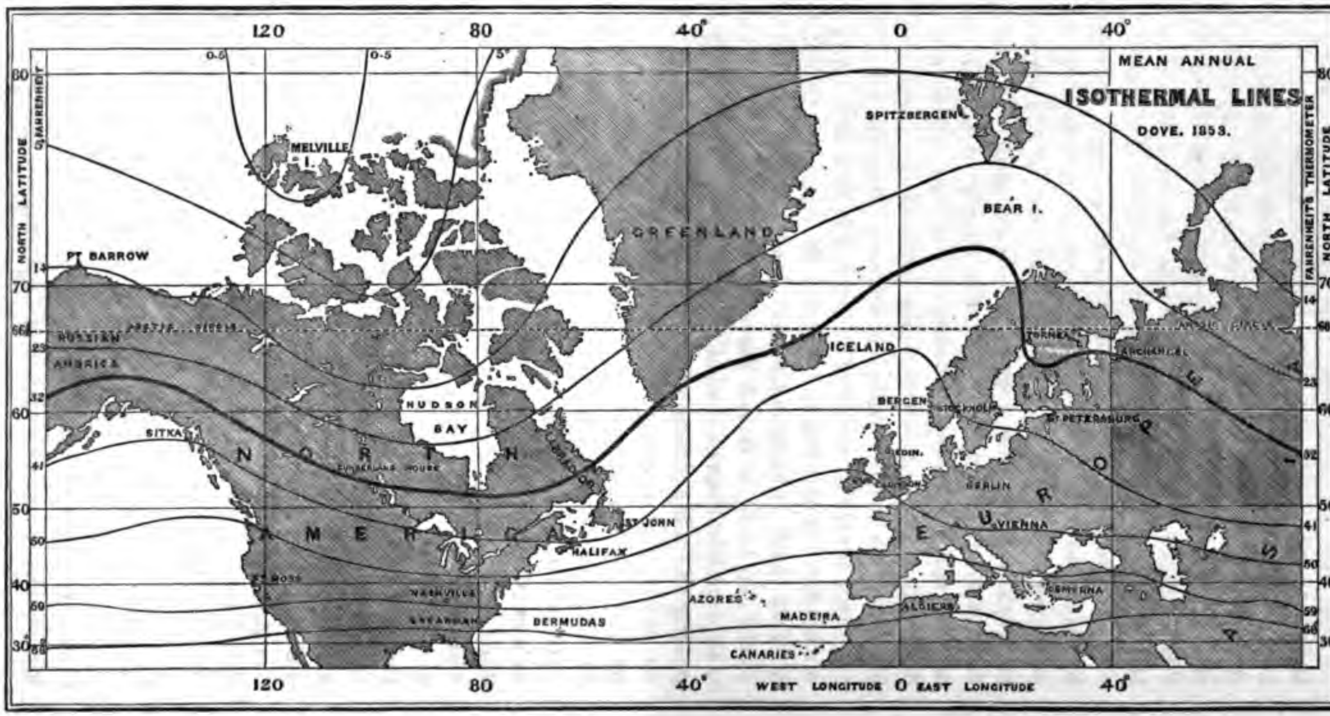
Another way in which the winds have a powerful, though indirect, influence on climate is by giving origin to the principal currents of the ocean. Humboldt, as we have seen (p. 237), assigned as a cause for the rigorous climate of Greenland

that it is connected with more northern latitudes by elevated land. But, besides this reason, it must be borne in mind that the eastern coast of that country is skirted for a thousand miles by the cold waters of the Greenland current flowing from the North Pole, while Lapland is warmed by the waters of the Gulf-stream flowing from the south.

It will be seen at p. 246 how much warmth is conveyed by this stream to the west of Europe, but the point which concerns us here is that if the land now at the equator in the region where the upper trade wind gains its heat and force were replaced by ocean, the supply of hot air would be less, and the average velocity of the trade winds would be diminished. Now the equatorial current of the North Atlantic is heaped up in the Caribbean Sea in a great measure by the confluent northern and southern trades, and any diminution of this force must lessen the head of water in the Gulf of Mexico, and consequently the force of the Gulf-stream. There can be little doubt therefore that the present abnormal preponderance of land at the equator has a great effect in raising the temperature of the surface of the globe, both by its continuity from tropical to temperate regions, and by its influence in increasing the warm aërial and oceanic currents.

In consequence of the more equable temperature of the waters of the ocean, the climate of islands and of coasts differs essentially from that of the interior of continents, the more maritime climates being characterised by mild winters and more temperate summers; for the sea breezes moderate the cold of winter, as well as the heat of summer. When, therefore, we trace round the globe those belts in which the mean annual temperature is the same, we often find great differences in climate; for there are *insular* climates in which the seasons are nearly equalised, and *excessive* climates, as they have been termed, where the temperature of winter and summer is strongly contrasted. The whole of Europe, compared with the eastern parts of America and Asia, has an 'insular' climate. The northern part of China, and the Atlantic region of the United States, exhibit 'excessive climates.' We find at New York, says Humboldt, the summer of Rome and the winter of Copenhagen; at Quebec, the

Fig. 9.


MEAN ANNUAL
ISOTHERMAL LINES
DOVE. 1853.
NORTH LATITUDE
FAHRENHEIT'S THERMOMETER
WEST LONGITUDE 0 EAST LONGITUDE
120
80
40°
0
40°
80
70
66½
60
50
40
30
PT BARROW
MELVILLE I.
RUSSIAN AMERICA
SITKA
NORTH AMERICA
HUDSON BAY
LABRADOR
ST JOHN
HALIFAX
NASHVILLE
SAVANNAH
BERMUDAS
GREENLAND
ICELAND
SPITZBERGEN
BEAR I.
AZORES
MADEIRA
CANARIES
BERGEN
STOCKHOLM
TORNEA
ARCHANGEL
ST PETERSBURG
EDIN.
LONDON
BERLIN
VIENNA
SMYRNA
ALGIERS
EUROPE
ARCTIC CIRCLE

summer of Paris and the winter of Petersburg. At Pekin in China, where the mean temperature of the year is that of the coasts of Brittany, the scorching heats of summer are greater than at Cairo, and the winters as rigorous as those of Upsala.

Mean annual isothermal lines.—If lines be drawn round the globe through all those places which have the same winter temperature, they are found to deviate from the parallels of latitudes much farther than the lines of equal mean annual heat. The lines of equal winter in Europe, for example, are often curved so as to reach parallels of latitude 9° or 10° distant from each other, whereas the isothermal lines of that continent, or those passing through places having the same mean annual temperature, differ only from 4° to 5°. If the reader will turn to the annexed map (fig. 9) by Professor Dove, he will see that the isothermal line of 32° Fr. or the freezing point of water, curves so as to vary as much as 14 degrees of latitude in passing from east to west, or from the south of Asiatic Russia (lat. 56°) to the north of Norway (lat. 70°). The same line then trends southward from Norway to Iceland, and passing to the southernmost point of Greenland, in lat. 60°, continues its course south-westwards to the south of Hudson's Bay, lat. 51° 15′, a point more than 18 degrees south of that which it had reached in the arctic sea. It then inclines again northwards through N. America to Behring's Straits.

The isothermal of 14° Fahr. is equally remarkable: passing from Siberia, about 50 miles south of Yakutsk, lat. 62° 2′ north, (which lies to the east of the limits of our map,) it inclines northwards to the north of Spitzbergen, in lat. 79°, then passes southwards through the north of Greenland, to 63°, in Hudson's Bay, reaching the same parallel from which it started in Siberia, then again it inclines north-westwards beyond the arctic circle till it reaches Point Barrow in Russian America, lat. 71° 40′. From such facts it is obvious that the curves of those lines in the same hemisphere which represent the same mean annual temperature are by no means dependent on astronomical causes or on latitude alone.

Dependence of the mean temperature on the relative position of land and sea.—When the meteorologist enquires into the state of things south of the equator, he finds the contrast of the temperature prevailing in certain lands similarly situated as regards their distance from the pole, equally striking, notwithstanding that, on the whole, there is a greater uniformity of climate in the southern hemisphere, in consequence of a greater predominance of sea over land. The most remarkable illustration of this contrast is afforded by the island of South Georgia, 800 miles due east of Tierra del Fuego, in latitude 54° S., or at the same distance from the equator as Yorkshire. Captain Cook, speaking of this island, says, in his second voyage, that in January (corresponding to our July) they never had the temperature more than 10° F. above freezing, and snow fell occasionally in the same month, the perpetual snows descending to the level of the ocean. No trees or shrubs were to be seen in summer, although here and there, after a partial melting of the ice on the coast, a few rocks were scantily covered with moss and tufts of grass.*

This state of things is remarkable when we reflect that the highest mountains in Scotland, nearly 4,500 feet high, and four degrees nearer the pole, do not retain snow even on their summits throughout the year; and Principal J. D. Forbes observed, that there is no place as yet known in the northern hemisphere where the snow-line comes down to the level of the sea.† The exact height of the mountains in S. Georgia is not known, but they are described as being very high, and in Sandwich Land, five degrees to the south, in a latitude corresponding nearly to the north of Scotland, mountains 10,000 feet high have been observed, and in those islands, on the 1st of February, the hottest time of the year, the whole country from the top of the mountains to the brink of the sea-cliffs was covered with snow many fathoms thick.

It was stated that Tierra del Fuego is only 800 miles west-

* Mr. Hopkins raises the question whether, in South Georgia, the descent of glaciers to the margin of the sea might not have been mistaken by Capt. Cook for the descent of the snow-line to the sea-level. Quart. Journ. Geol. Soc. p. 85. 1852. But the great navigator is generally so accurate that I see no reason for calling his statements in question.

† J. D. Forbes, Norway, p. 205.

ward of S. Georgia. As it is in the same latitude, as well as in the same hemisphere, the contrast in climate which it presents must be quite independent of what we may term astronomical causes. In Tierra del Fuego the lower limit of the snow-line ascends, according to Darwin, to between 3,000 and 4,000 feet above the level of the sea, and there are forests on the flanks of the hills to a height of 1,000 or 1,500 feet.* There are many flowers in the same region and humming-birds in summer, yet a high range of land runs across the middle of Tierra del Fuego from east to west, reaching at one point, in Mt. Sarmiento, a height of 6,000 feet. Glaciers also descend to the sea on the Patagonian side in lat. 53°, at a point where the strait intersects the main chain of mountains which continues the Andes into Tierra del Fuego. Floating icebergs moreover abound off Cape Horn, where no less than 2,000 of them are sometimes counted in the spring season. There may, perhaps, be a still greater number of icebergs coming from the antarctic continent to that part of the ocean which surrounds S. Georgia; but the chief cause of the difference in climate between S. Georgia and Tierra del Fuego is probably the presence of the neighbouring low region of Patagonia, which causes in a great part of the year the winds from the north to be heated to an extent which the atmosphere can never acquire when passing over the sea which extends for twenty degrees north of S. Georgia.

Dr. Hector has remarked† that the north-west winds, when they blow for several days in succession from Australia to the southern island of New Zealand, are so hot and dry as to cause great floods by the sudden melting of the snow on the southern Alps of that island. He observes that if Australia were submerged, or if, at some former period, the sea covered a larger portion of the space now occupied by that continent, the New Zealand glaciers, which are now of considerable size, would have been more voluminous. I call the reader's attention to this fact, because, in speculating on a change of climate due to altered geographical conditions, it is too often

* Darwin's Journal, pp. 145, 209.

† Letter to Dr. J. Hooker, July 15, 1864.

assumed that the alteration must have taken place in the immediate region where the temperature has been modified.

Cold of the antarctic regions.—The cold of the antarctic regions was conjectured by Cook to be due to the existence of a large tract of land between the 70th degree of south latitude and the pole. The soundness of these and other speculations of that great navigator has since been singularly confirmed by the exploring expedition of Sir James Ross in 1841. He observed that the temperature south of the 60th degree of latitude seldom rose above 32° Fahr. During the two summer months (January and February) of the year 1841, the range of the thermometer was between 11° and 32° Fahr.; and scarcely once rose above the freezing point. He also ascertained that Victoria Land, extending from 71° to 79° south latitude, was skirted by a great barrier of ice in lat. 78° south, which rose only 150 feet above water, and he estimated its total thickness, above and below water for about 600 miles, to be not more than 1,000 feet, and here the height of the inland country ranges from 4,000 to 15,000 feet, as in Mt. Melbourne. This elevated region is opposite New Zealand and Tasmania; the whole of it was entirely covered with snow, except a narrow ring of black earth (scoriæ?) surrounding the huge crater of Mt. Erebus, an active volcano, which rises 12,400 feet above the level of the sea. Another part of the antarctic land, namely, that which approaches nearest to South America or Cape Horn, as, for example, Graham's Land, and Louis Philippe Land, reaches also a great altitude, namely, from 4,000 to 7,000 feet. The existence of such heights and of so vast an area of land—probably exceeding in dimensions the whole of Australia—may well account for the intense cold, which reaches to the 60th degree of latitude, and sometimes farther, towards the equator in the southern hemisphere. Captain Biscoe, in 1831–2, describes Graham's and Enderby's Lands, between latitudes 64° and 68° south, as presenting a most wintry aspect in summer, and as being nearly destitute of animal life. In corresponding latitudes of the northern hemisphere, owing chiefly to the influence of the Gulf-stream, we not only meet with herds of wild herbivorous animals, but with land (Lapland, Iceland,

and Greenland) which man himself inhabits, and where he has even built ports and inland villages.

The chief causes of the intense cold of high southern latitudes are twofold: first, the vast height and extent of the antarctic continent; and secondly, what is no less important, the almost entire absence of land in the South Temperate Zone, where its presence would warm the atmosphere. It may undoubtedly be said, that some part of the cold of south polar latitudes is due to the fact that its winters occur when the earth is at its greatest distance from the sun, and they are eight days longer than the winters of the northern hemisphere. That this cause is not without its effect in somewhat augmenting the quantity of antarctic ice, even with the present moderate excentricity of the earth's orbit, is most probable, and the amount might be increased if a still larger excentricity happened to coincide with land of equal extent and elevation at the South Pole; but I shall endeavour to show in the next chapter, that the influence of excentricity will always be quite subordinate to geographical conditions in determining climate.

Effect of currents in equalising the temperature of high and low latitudes.—The dominant influence of the position of land in reference to north polar temperature is well shown by the fact that there is open sea nearer the pole than the northern extremity of Greenland. Antecedently to experience it might have been thought that the thickness of the ice would increase as it extended northwards; but Parry penetrated within about seven degrees, and Kane within five degrees, of the North Pole, and they both of them found open sea there, though they had reached a latitude so much higher than that in which the continent of Greenland is enveloped in a winding-sheet of perpetual snow and ice. From such facts the geologist may learn that, although in the Glacial epoch certain mountain-chains and adjoining low-lands may have been buried in temperate latitudes under a vast covering of ice, yet the waters of the ocean in much higher latitudes may not at the same period have been frozen. We are by no means called upon as geologists to embrace the opinion that an ice-cap once reached continuously from the pole to lat.

50°, still less to 40° in the temperate zone. It has long been a favourite opinion of northern voyagers that there is open sea during part of the year at the pole itself, and the observations of Eschricht and Reinhardt on the migrations of the Greenland whale are rather confirmatory of this idea. It appears that this northern whale, *Balæna Mysticetus*, is different from the whale called *B. Biscayensis*, a species now almost extirpated, and which once inhabited the British seas and the Bay of Biscay. In winter the Greenland whales accompany the ice when it floats farthest to the south in Baffin's Bay, but in the summer, when the ice is only to be found farther north, they migrate to parts of the sea nearer the pole, having been seen as far north as man has yet penetrated. Apparently they retreat to the polar sea, which cannot therefore be covered by a continuous sheet of ice, for in that case they would be suffocated, since they must occasionally come to the surface to breathe. They could, however, pass under considerable barriers of ice provided there were openings here and there; and so they may perhaps reach a more open sea near the pole, and find sustenance there during a day of more than five months' duration. This open sea is partly due to marine currents, by which the seas of higher and lower latitudes exchange their warm and cold waters. Of the equalising effect of such currents, as regards temperature, the Gulf-stream, which is chiefly caused, as we shall see in Chapter XX. by the trade winds, affords the best illustration. The waters of the Gulf of Mexico were calculated by Rennell to attain in summer a temperature of 86° Fahr., and more lately (in 1860) Prof. Bache estimated their temperature in June at 84° F., or 8° above that of the Atlantic in the same latitude. From this great reservoir or caldron of warm water, a constant current pours forth through the straits of Bahama at the rate of three or four miles an hour. According to Prof. Bache, it is twenty-five miles wide off Cape Florida, and its width increases to 127 miles off Sandy Hook, in lat. 40° 30′. Here it has a temperature of 80° F. for a depth of 15 fathoms, or 90 feet, a heat retained in one place as far down as 100 fathoms, while it continues to be 50° F. to a depth of 500 fathoms. Between

it and the land for the whole length of the eastern coast of the United States flows a cold current in an opposite direction varying in width, but usually more than 200 miles wide, and having a temperature of only 40° F.; * so that here we see an active transference continually going on, of tropical heat to the poles and of polar cold to the tropics. Large icebergs coming from Baffin's Bay, having their lower parts immersed in the colder current, move southwards in spite of the opposite direction in which the superficial stream is running, and sometimes in direct opposition to a wind from the south. When the Gulf-stream skirts the great bank of Newfoundland, it still retains a temperature of 8° above that of the surrounding sea. In about seventy-eight days it reaches the Azores, after flowing nearly 3,000 geographical miles, and here it has, according to Dr. Petermann, a temperature of 81° F. From thence it extends its course a thousand miles farther, so as to reach the Bay of Biscay, still retaining an excess of .5° above the mean temperature of that sea. As it has been known to arrive there in the months of November and January, it must tend greatly to moderate the cold of winter in countries on the west of Europe. Passing on to the south-west of the Faroe islands, lat. 59° 35′, it still retains a heat of 51° F. at the surface, and 44° F. at a depth of 500 fathoms. Its further course has been minutely and carefully worked out by Dr. Petermann, in accordance with the results of all the exploring expeditions made up to the year 1870, by means of which he traces it to Nova Zembla with a heat of 36° 5′ F., and beyond this with a diminishing temperature into the Polar Basin.†

In the centre of the North Atlantic there is a large tract, between the parallels of 33° and 45° N. lat., which Rennell called the 'recipient of the Gulf water.' This mass of water is nearly stagnant, is warmer by 7° or 10° than the waters of the Atlantic, and may be compared to the fresh water of a river overflowing the heavier salt water of the sea. Rennell estimates the area of the 'recipient,' together with that

* Bache on the Gulf-stream.—American Journal of Science, 1860.

† Petermann, 'Der Golfstrom etc.,' Geographische Mittheilungen, 16. Band, 1870, Nos. VI. and VII.

covered by the main current, as being 2,000 miles in length from E. to W., and 350 in breadth from N. to S., which, he remarks, is a larger area than that of the Mediterranean. The heat of this great body of water is kept up by the incessant and quick arrivals of fresh supplies of warm water from the south; and there can be no doubt that the general climate of parts of Europe and America is materially affected by this cause.

Principal J. D. Forbes calculated that the quantity of heat thrown into the Atlantic Ocean by the Gulf-stream on a winter's day would raise the temperature of the atmosphere which rests on France and Great Britain from the freezing point to summer's heat.* Scoresby remarked that the influence of the Gulf-stream extends to Spitzbergen, in the 79° of N. latitude, and that the great glaciers which fill all the valleys of that island are cut off abruptly at the beach by the remnant of heat which the ocean still derives from this source.

In Baffin's Bay, on the west coast of Greenland, where the temperature of the sea is not mitigated by the same cause, the glaciers stretch out from the shore, and furnish repeated crops of mountainous masses of ice which float off into the ocean.† The number and dimensions of these bergs are prodigious. Capt. Sir John Ross saw several of them together in Baffin's Bay aground in water 1,500 feet deep! Many of them are driven down into Hudson's Bay, and, accumulating there, diffuse excessive cold over the neighbouring continent; so that Sir John Franklin reported, that at the mouth of Hayes' River, which lies in the same latitude as the north of Prussia or the south of Scotland, ice is found everywhere in digging wells, in summer, at the depth of four feet! It is a well-known fact that every four or five years a large number of icebergs, floating from Greenland, are stranded on the west coast of Iceland. The inhabitants are then aware that their crops of hay will fail, in consequence of fogs which are generated almost incessantly;

* Travels in Norway, p. 202.

† Scoresby's Arctic Regions, vol. i. p. 208.—Dr. Latta's Observations on the Glaciers of Spitzbergen, &c. Edin. New Phil. Journ. vol. iii. p. 97.

and the dearth of food is not confined to the land, for the temperature of the water is so changed that the fish entirely desert the coast.

In the northern hemisphere icebergs are constantly floated as far south in the Atlantic as the latitude of Madrid in Europe, or New York in America; the farthest point to which they are habitually carried lies to the S.E. of Newfoundland, in mid-ocean, and about half-way between the Azores and New York, in W. long. 45°. In the southern hemisphere they float to latitudes several degrees nearer the equator, as, for example, to points off the Cape of Good Hope between lat. 36° and 39°.* One of these (see fig. 10) was two miles in circumference, and 150 feet high, appear-

Fig. 10.

Iceberg seen off the Cape of Good Hope, April 1829.
Lat. 39° 13′ S. Long. 48° 46′ E.

ing like chalk when the sun was obscured, and having the lustre of refined sugar when the sun was shining on it. Others rose from 250 to 300 feet above the level of the sea, and were therefore of great volume below; since it is ascertained, by experiments on the buoyancy of ice floating in sea water, that for every cubic foot seen above there must at least be eight cubic feet below water, but it will depend on the shape of the berg and the position of its centre of gravity to what depth under water the mass will extend.† If ice islands from the north polar regions floated as far towards the equator as they do in the southern hemisphere, they might reach Cape St. Vincent, and there, being drawn by the current that always sets in from the Atlantic through

* On Icebergs in Low Latitudes, by Capt. Horsburgh, by whom the sketch was made. Phil. Trans. 1830.

† Rennell on Currents, p. 95.

the Straits of Gibraltar, be drifted into the Mediterranean, so that the serene sky of that delightful region might soon be deformed by clouds and mists.

The current which flows from the Indian Ocean through the Mozambique Channel, having a breadth of nearly a hundred miles and a velocity varying from two to four miles an hour, conveys warm water from a tropical to a temperate region. A current which flows in an opposite direction from Cape Horn northwards, along the west coast of South America, conveys colder water towards the tropics.

These oceanic rivers, as they have been called, exercise a great control over the temperature of the air in certain areas, causing deviations in the isothermal lines already alluded to (p. 241). Their course being to a great extent dependent on the position of the land, they add greatly to the influence which geographical conditions exert on the state of the climate at any given period. For instance, the waters in the Gulf of Mexico, which are driven westward and piled up by the continued influence of the east wind, are now deflected back by the Isthmus of Panama. But it is obvious that if this isthmus had no existence these waters would flow on westward into the Pacific Ocean instead of giving origin to the Gulf-stream. And as the watershed of the isthmus is in one part only 250 feet above the level of the sea, the breach here supposed is no extravagant speculation, but would be effected by a change of level not greater than we can show to have occurred in parts of the British isles since the commencement of the Glacial Period.

Present proportion of polar land abnormal.—It has been well said, that the earth is covered by an ocean, in the midst of which are two great islands and many smaller ones; for the whole of the continents and islands occupy about two-sevenths, or a little more than one-fourth, of the whole superficies of the spheroid; the area of the sea to that of the land being as two and a half to one. Now, according to this analogy, we may fairly speculate on the probability that there would not be usually, at any given epoch of the past, more than about one-fourth dry land in a particular region; as, for example, near the poles, or between them and

the 60th parallels of N. and S. latitude. If, therefore, at present there should happen to be, in both these quarters of the globe, much *more* than this average proportion of land, if the land should actually be equal in area to the sea, and some of it in the arctic region 8,000 feet in height, and in the antarctic 15,000 feet, this alone affords ground for concluding that, in the present state of things, the mean heat of temperate and polar regions is far below that which in a more ordinary state of the earth's surface they would enjoy.

This presumption is greatly heightened when we discover that there is a deficiency of land between the tropics, where, in consequence of its being exposed to the direct, or nearly direct, rays of the sun, it would produce the greatest heat. For in the inter-tropical regions of the globe the sea is to the land as four to one, instead of two and a half to one. It is clear, therefore, that we have at present not only more than the usual degree of cold in the polar regions, but also less than the average quantity of heat within the tropics.

The reader will at once perceive that if it be a legitimate speculation on the part of the geologist to assume, that in past times the polar regions had usually within them the normal proportion of sea and land, of two and a half to one, between lat. 60° and the poles, instead of so abnormal a proportion as one to one, the climate of the temperate regions would be much warmer; and if there were periods when a deep ocean interspersed with a few islands prevailed at both poles (an event which would probably not be rare), there might be an entire absence of permanent snow and ice, even on the summit of the highest mountains. If such were the case, there would still be oceanic currents causing an exchange of temperature between high and low latitudes, but none of them would convey floating ice to lower the temperature of the sea between the arctic and antarctic circles and the tropics. In the present geographical state of the globe, the Alps, in latitude 46°, are covered with perpetual snow, and even under the equator itself a mountain 20,000 feet high has lately been discovered in Eastern Africa, which has its uppermost 4,000 feet always above the lowest

limit of snow; * but these mountainous heights would be very differently circumstanced if the aërial currents which circulate freely from polar to equatorial latitudes were not reduced in temperature by the wide extent of snow and ice now prevailing in both polar areas at all seasons of the year.

Succession of geographical changes revealed to us by geology.—To those whose attention has never been called to the former changes in the earth's surface which geology reveals to us, the position of land and sea appears fixed and stable. It may not seem to have undergone any material alterations since the earliest times of history; but when we enquire into the subject more closely, we become convinced that there is annually some small variation in the geography of the globe. In every century the land is in some parts raised, and in others depressed in level, and so likewise is the bed of the sea. By these and other ceaseless changes, the configuration of the earth's surface has been remodelled again and again, since it was the habitation of organic beings, and the bed of the ocean has been lifted up to the height of some of the loftiest mountains. The imagination is apt to take alarm when called upon to admit the formation of such irregularities in the crust of the earth, after it had once become the habitation of living creatures; but, if time be allowed, the operation need not subvert the ordinary repose of nature; and the result is in a general view insignificant, if we consider how slightly the highest mountain-chains cause our globe to differ from a perfect sphere. Chimborazo, though it rises to more than 21,000 feet above the sea, would be represented, on a globe of about six feet in diameter, by a grain of sand somewhat less in diameter than the letter o in this type.

The superficial inequalities of the earth, then, may be deemed minute in quantity, and their distribution at any particular epoch must be regarded in geology as temporary peculiarities, like the height and outline of the cone of

* Kellimandjaro, discovered by Dr. Redmann in 1848, and measured in 1862 by Baron Von der Decken, who found it to be 20,065 feet high. Geograph. Journ. vols. xxxiv. xxxv

Vesuvius in the interval between two eruptions. But although, in reference to the magnitude of the globe, the unevenness of the surface is so unimportant, it is on the position and direction of these small inequalities that the temperature of the atmosphere and the sea, and the circulation both of the aërial and oceanic currents, are mainly dependent.

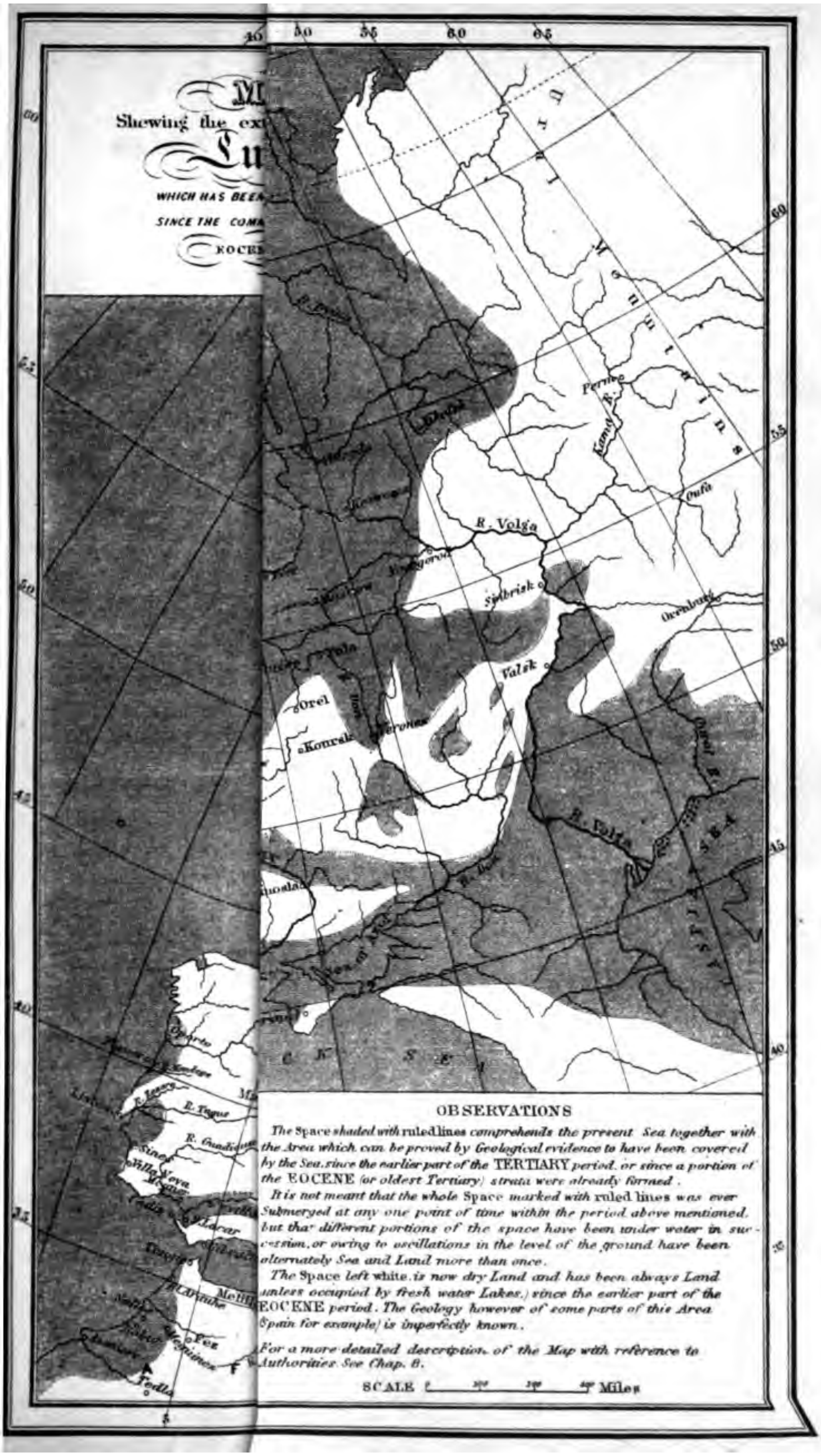
Before I insist on the great fluctuations in temperature, to which the ever-varying form of the earth's crust must inevitably give rise, it will be desirable to say something of those geographical changes which are demonstrated by our geological records to have taken place. The reader has been in some degree prepared for the contemplation of such revolutions by what we have said in our retrospective survey of former states of the animate creation as bearing on climate. He has been told that even since the commencement of the Glacial Period, when the living species of testacea and most of the existing animals and plants were in being, great changes in the height of European lands have occurred; what was formerly the bed of the sea having been raised, together with its marine shells, to elevations of 500 and even 1,400 feet, and corresponding subsidences, attended by the submergence of much ancient land, having taken place within an era so modern in the history of the earth. In one part of this Glacial Period we find proofs that England and Ireland were united to each other, and to the continent, while at other times they were broken up into an archipelago of small islands; we also find that large parts of Northern Germany, and Russia, were beneath a sea often covered with floating ice; and that the Desert of the Sahara was under water between lats. 20° and 30° N., so that the eastern part of the Mediterranean communicated with that part of the ocean now bounded by the west coast of Africa. The Atlantic also penetrated far into what is now the basin of the St. Lawrence, and the White Mountains in New Hampshire constituted an archipelago. In short, a map of the Northern Hemisphere, even in glacial times, would bear but a distant resemblance to our present maps of the same region, and so far as we are acquainted with the geology of

equatorial countries, they have undergone an equal amount of alteration. This may be seen by anyone who will consult Darwin's map of coral reefs and active volcanos, which shows how many large areas have been the theatres, some of subsidence, others of elevation on a great scale, while the species of shells and corals of the Atlantic and Pacific have remained unchanged. The continent of South America, from lat. 34° S. to Patagonia, appears also to have been upraised throughout its entire width, since the beginning of the Post-tertiary period. The geographical distribution of the quadrupeds, birds, and insects in the islands of the Malay Archipelago has enabled Mr. Wallace to demonstrate the former union of those islands with each other and with the mainland since the present species were in being. He has shown that the Indian fauna exhibits an abundance of species common to both sides of those straits, wherever the depth does not exceed 100 fathoms, whereas if the soundings are deeper, even though the separated lands be in sight of each other, the birds and mammalia are quite distinct.*

If we reflect on these facts, and consider what a brief space of time the Post-tertiary era constitutes as compared to the whole of the Pliocene period, and if we then endeavour to form an idea of the duration of the antecedent Eocene and Miocene epochs by reference to the greater changes in organic life of which they afford evidence, we shall be prepared to find that a map representing the position of the land and sea in the earliest division of the Eocene period will be wholly unlike the picture which corresponding portions of the globe now present.

In the accompanying map (Plate I.) the proofs of submergence, during the period alluded to, in all the districts distinguished by ruled lines, are of a most unequivocal character; for the areas thus indicated are now covered by deposits containing the fossil remains of shells and other creatures which could only have lived in salt water. The most ancient part of the period referred to cannot be deemed very remote, considered geologically; because the deposits of the Paris

* Wallace, A., Physical Geography of Malay Archipelago, Journ. of Roy. Geograph. Soc. 1864.



OBSERVATIONS

The Space shaded with ruled lines comprehends the present Sea together with the Area which can be proved by Geological evidence to have been covered by the Sea, since the earlier part of the TERTIARY *period, or since a portion of the* EOCENE *(or oldest Tertiary) strata were already formed.*

It is not meant that the whole Space *marked with* ruled lines *was ever Submerged at any one point of time within the period above mentioned, but that different portions of the space have been under water in succession, or owing to oscillations in the level of the ground have been alternately Sea and Land more than once.*

The Space *left* white, *is now dry Land and has been always Land (unless occupied by fresh water Lakes,) since the earlier part of the* EOCENE *period. The Geology however of some parts of this Area (Spain for example) is imperfectly known.*

For a more detailed description of the Map with reference to Authorities See Chap. 8.

and London basins, and many other districts belonging to the older Tertiary epoch, are newer than the greater part of the sedimentary rocks, those commonly called Secondary and Primary (Mesozoic and Palæozoic), of which the crust of the globe is composed. Yet, notwithstanding the comparatively recent epoch to which this retrospect is carried, the variations in the distribution of land and sea depicted on the map form only a part of those which must have taken place during the same period. An approximation merely has been made to an estimate of the amount of *sea converted into land* in parts of Europe best known to geologists; but we cannot determine how much land has become sea during the same period; and there have been repeated interchanges of land and water in the same places, of which no account could be taken.*

I was anxious, even in the title of this map, to guard the reader against the supposition that it was intended to represent the state of the physical geography of part of Europe at any *one point of time*. The difficulty, or rather the impossibility, of restoring the geography of the globe as it may have existed at any former period, especially a remote one, consists in this, that we can only point out where part of the sea has been turned into land, and are almost always unable to determine what land may have become sea. All maps, therefore, pretending to represent the geography of remote geological epochs must be to a great extent ideal. The map under consideration is not a restoration of a former state of things at any particular moment of time, but a synoptical view of a certain amount of one kind of change (the conversion of sea into land) known to have been brought about within a given period.

The vertical movements to which the land is subject in certain regions, consist of the alternate subsidence and uprising of the surface; and by such oscillations at successive

* In compiling this map I have availed myself of the government surveys of England, France, and Germany, and of the important map of Russia, published by Sir Roderick Murchison, M. de Verneuil. and Count Keyserling. M. de Verneuil's excellent map of Spain has also enabled me to extend the ruled lines over part of that country where before his survey no tertiary strata were supposed to exist.

periods, a great area may have been entirely covered with marine deposits, although the whole may never have been beneath the waters at one time; nay, even though the relative proportion of land and sea may have continued unaltered throughout the whole period. I believe, however, that since the commencement of the Tertiary period the dry land in the northern hemisphere has been continually on the increase, both because it is now greatly in excess beyond the average proportion which land bears to water on the globe generally, and because a comparison of the Secondary and Tertiary strata affords indications of a passage from the condition of an ocean interspersed with islands to that of a large continent.

But supposing it were possible to represent all the vicissitudes in the distribution of land and sea that have occurred during the Tertiary period, and to exhibit not only the actual existence of land where there was once sea, but also the extent of surface now submerged which may once have been land, the map would still fail to express all the important revolutions in physical geography which have taken place within the epoch under consideration. For the oscillations of level, as was before stated, have not merely been such as to lift up the land from below the water, but in some cases to occasion an additional rise of tracts which had already emerged. Thus the Alps have acquired 4,000, and even in some places more than 10,000 feet of their present altitude since the commencement of the Eocene period; and the Pyrenees have attained their present height, which in Mont Perdu exceeds 11,000 feet, since the deposition of the nummulitic or Eocene division of the Tertiary series. Some of the Tertiary strata at the base of the chain are only a few hundred feet above the sea, and retain a horizontal position, without partaking in general in the disturbances to which the older series has been subjected; so that the great barrier between France and Spain was almost entirely upheaved in the interval between the deposition of certain groups of Tertiary strata.

On the other hand, some mountain-chains may have been lowered during the same lapse of ages, in an equal degree,

and shoals have probably been converted into deep abysses, as seems decidedly to have taken place in the Mediterranean. Geologists are now agreed that the limestone and associated strata called nummulitic belong to the Eocene group; as these rocks enter into the structure of some of the most lofty and disturbed parts of the Alps, Apennines, Carpathians, Pyrenees, and other mountain-chains, and form many of the elevated lands of Africa and Asia, their position almost implies the ubiquity of the Eocene ocean in regions which are now dry land, not, indeed, by the simultaneous, but by the successive, occupancy of the whole ground by its waters.*

Antiquity of existing continents.—It is perfectly consistent with the preceding observations to affirm that our present continents are extremely ancient. They have all of them, it is true, undergone many minor modifications in their form even in post-tertiary times, some parts of them having been submerged, and others so much raised as to have been united with what are now islands lying at some distance from them. But the principal masses of land have continued so long above water, that each of them is now tenanted by a distinct set of animals and plants. More than this: we find, when we examine the fossil remains of land quadrupeds of Pliocene date proper to each continent, that although they may be of extinct species, they are allied in structure to the living mammalia of the same region. Extinct species of kangaroo, for example, and of other marsupials, preceded the living marsupials on the Australian continent. In like manner, species of elephant and rhinoceros, and of catarrhine monkeys, of forms no longer in existence, inhabited India in Miocene and Pliocene times, before the living representatives of the same genera and families were in being; while, in the New World, the platyrrhine quadrumana and the sloths, armadillos, and other South American forms belonging to an extinct fauna, flourished in times immediately antecedent to those of the recent mammalia of the same continent.

* See Sir R. Murchison's Paper on the Alps, Quart. Journ. Geol. Soc. vol. v.; and my Anniversary Address for 1850, ibid. vol. vi.

The complete dissimilarity, also, of the marine fauna on the opposite sides of several continents attests the permanence of the great barriers of land, which have, from a remote age, prevented the migration of fish, mollusca, and other aquatic tribes from one sea to the other. But the distinctness of these marine provinces does not go back to the Lower Miocene period; and even when we carry back our retrospect to the Upper Miocene, we find evidence that the mollusca and corals of the Atlantic and Pacific Oceans by no means belonged to such distinct assemblages of species as they do now. There must have been up to that time a communication through the Isthmus of Panama, as is proved by the study of the corals and marine shells of the West Indian islands.* If we go back still further—to the terrestrial plants and animals of the Eocene period—we find such a mixture of forms now having their nearest living allies in the most distant parts of the globe, that we cannot doubt that the distribution of land and sea bore scarcely any resemblance to that now established, while in regard to the ocean of that era, what we have said (p. 207) of marine strata of the Eocene period shows how many mountain-chains forming the backbones of the present continents were submerged when the marine fauna of that period were already in existence.

Continents therefore, although permanent for whole geological epochs, shift their positions entirely in the course of ages. The great slowness with which the change is always brought about results from a peculiarity in the external configuration of the earth's crust, which I shall point out in the sequel of this chapter (see p. 268).

Both in the eastern and western hemispheres north of the equator, when we carry our retrospect beyond the limits of the tertiary rocks, and pass on to the antecedent cretaceous formations, we find abundant proofs of an open sea in regions which are now continental. In the oldest part of this period in the south of England, we find in the Wealden strata the memorials of the delta of a large river, implying a contour

* See Papers by John Carrick Moore, Esq., and Dr. Duncan, referred to in Elements of Geology, 6th edition, 1865, p. 271.

of land and sea which has no reconcilable relation to existing geographical conditions; and it is worthy of note that, although the foundations of this delta sank during the accumulation of the fluviatile strata as much as 1,000 or sometimes 1,500 ft., yet there continued to be land in the neighbourhood in the south-east of England; which can scarcely be explained except by supposing that an upward movement was taking place in the vicinity of a downward one, or that adjoining parts of the surface were moving slowly in opposite directions.

The frequent unconformability of strata of different ages is a proof that if we had a series of maps, in which restorations of the physical geography of thirty or more periods were depicted, they would probably bear no more resemblance to each other or to the actual position of land and sea, than does the map of one hemisphere at present bear to that of the other.

The height to which ammonites, shells, and corals have been traced in the Alps, Andes, and Himalaya is sufficient to show that the materials of all those chains were elaborated under water, and some of them in seas of no slight depth. Beds of coal, in the ancient carboniferous formation, attest the former existence of land, since the plants from which they are derived must have grown on low swamps covered with forests. The sand and shales which over- and under-lie them must have been formed at the termination of large hydrographical basins, each drained by a great river and its tributaries; and the accumulation of sediment bears testimony to contemporaneous denudation on a large scale, and, consequently, to an area of land probably containing within it one or more mountain-chains.

In the case of the great Ohio or Appalachian coal-field, the largest in the world, it seems clear that the uplands drained by one or more great rivers were chiefly to the eastward, or occupied a space now covered by the Atlantic Ocean, for the mechanical deposits of mud and sand increase greatly in thickness and coarseness of material as we approach the eastern borders of the coal-field, or the south-east flanks of the Alleghany Mountains, near Philadelphia—in other words,

as we get nearer to the Atlantic. In that region numerous beds of pebbles, often of the size of a hen's egg, are seen to alternate with beds of pure coal.

It has also been observed, in reference not only to the Carboniferous but to the antecedent Devonian and Silurian rocks of North America, that all the mechanical deposits as we travel from the Atlantic border to the Mississippi, diminish constantly in thickness, while the limestones and rocks of organic origin or open-sea deposits, with corals and encrinites, increase and replace the others.

But the American coal-fields are all comprised within the 30th and 50th degrees of north latitude; and there is no reason to presume that the lands at the borders of which they originated ever penetrated so far, or in such masses, into the colder and arctic regions, as to generate a cold climate. One of the members of the Carboniferous group, the mountain limestone, was of marine origin, and its occupancy of large areas in Europe and the United States, and in parts of North America bordering the Arctic Sea, makes it quite conceivable that there may have been such a condition of things at the period of the coal as might give rise to a general warmth and uniformity of climate throughout the globe.

The Silurian strata now constituting parts of many upland or mountainous regions in Europe and America were formed for the most part in deep seas far from land, which may account for their being almost entirely destitute of the remains of terrestrial plants.

Present unequal distribution of land and sea.—Without dwelling longer on the proofs with which geology supplies us of former changes in physical geography, it is not too much to say that every spot which is now dry land has been sea at some former period, and every part of the space now covered by the deepest ocean has been land. The present distribution of land and water encourages us to believe that almost every conceivable transformation in the external form of the earth's crust may have been gone through. In one epoch the land may have been chiefly equatorial, in another for the most part polar and circumpolar. At one period most of it may have been north of the line, in another south of it; or

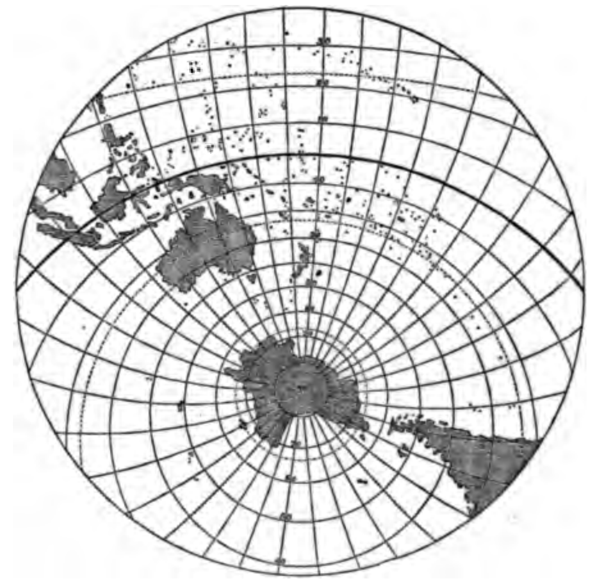
at one time all in the west, at another the whole of it in the east. In illustration of this point, it may be well to state that there is now just twice as much land in the eastern as there is in the western hemisphere; and even assuming the existence of an antarctic continent, more than twice as much land north of the equator as south of it. But what is most singular, as showing the capricious distribution of the land in the present state of the earth's crust, we find it possible so to divide the globe into two equal parts, that one hemisphere shall contain as much land as water, while the other is so oceanic that the sea is to the land very nearly as 8 to 1.* This is shown by projecting the hemispheres on the plane of the horizon of a point in lat. 52° N. and in long. 6° W. of Greenwich (see p. 262). The point alluded to is situated in St. George's Channel, about midway between Pembroke and Wexford, and the eye of the observer is supposed to be so placed above it as to see from thence one half of the globe. In such a position he would behold at one view the greatest possible quantity of land, or, if transferred to the opposite or antipodal point, the greatest possible quantity of water.

In previous editions I used, in illustration of the same subject, a map projected for me by the late Mr. James Gardner on the horizon of London, for he regarded that metropolis as the centre of the Land hemisphere. The maps now presented to the reader have been executed by Mr. Trelawny Saunders, who has so divided the globe as to add to the Land hemisphere part of S. America, including a portion of the Peruvian coast, while an equivalent area of the China Sea is transferred to the Water hemisphere. Intimately connected with the excess of land in the one hemisphere as compared to that in the other is the fact that, even allowing for the antarctic continent as expressed in the map, only one-thirteenth part of the dry land has any land directly opposite to it. Thus, in fig. 11 the land shaded black between the China Sea and Lake Baikal answers to that portion of S. America and Tierra del Fuego which is antipodal to it. Farther north, a part of the continent of Asia,

* The exact proportion of land to sea, as calculated by Mr. Saunders, is 1 to 1·106 in the Land Hemisphere, and 1 to 7·988 in the Water Hemisphere.

Fig. 11.

Fig. 12.



MAP SHOWING THE PRESENT UNEQUAL DISTRIBUTION OF LAND AND WATER ON THE SURFACE OF THE GLOBE.

Fig. 11. Here a point in St. George's Channel, midway between Pembroke and Wexford, is taken as a centre, and we behold the greatest quantity of land existing in one hemisphere.

Fig. 12. Here the centre is the antipodal point to that taken in Fig. 11, and we see the greatest quantity of water existing in one hemisphere.

extending along the arctic sea, as well as a large tract of Greenland and other arctic lands shaded in the same manner, are antipodal to the antarctic continent. The dark spots in South America represent tracts antipodal to Java, Borneo, Celebes and the Philippines, a part of Sumatra, and the Malay peninsula. The specks in Africa bear a similar relation to the islands in the Pacific Ocean, and the dark patches in Spain and Morocco mark those countries as partially antipodal to New Zealand.

The limits of the supposed antarctic continent have been drawn with reference to the known position of Victoria, Wilkes', Enderby's, and Graham's Lands, and the points where Ross, Weddell, and other navigators were stopped by the ice; but in order not to exaggerate the proportion of dry land in the unexplored area, I have assumed one-eighth of it to be sea. This reduction has been made by extending the basin of the ocean somewhat nearer the pole than the points to which our navigators have yet penetrated, both between Graham's and Enderby's Lands and between the latter and Termination Land, in the former of which regions the ships were usually stopped by pack-ice before reaching the 70th, and in the other the 65th degree of latitude. On the other hand, I have thought it safer not to represent all the unexplored area at the N. Pole as sea; and have therefore given one-eighth of it as land, which has been done by introducing several supposed islands in the open sea said to exist off the Russian coast, and off the N.W. of Greenland.

Former geographical changes which may have caused the fluctuations in climate revealed to us by geology.—Having now shown the reader that there have been endless changes in the form of the earth's crust in geological times, whereby the position as well as the height and depth of the land and sea has been made to vary incessantly, and that on these geographical conditions the temperature of the atmosphere and of the ocean in any given region and at any given period must mainly depend, I shall next proceed to speculate on the nature of the changes which, if assumed, might account for the leading facts revealed to us by geology as explained in the last two chapters.

In order that our speculations may be confined within the strict limits of analogy, I shall assume, 1st, That the proportion of dry land to sea continues always the same. 2ndly, That the volume of the land rising above the level of the sea is a constant quantity; and not only that its mean, but that its extreme height, is liable only to trifling variations. 3rdly, That on the whole, and in spite of local changes, both the mean and extreme depth of the sea are invariable; and 4thly, That the grouping together of the land in continents is a necessary part of the economy of nature. I think it consistent with due caution to make this last assumption, because it is possible that the laws which govern the subterranean forces, and which act simultaneously along certain lines, cannot but produce at every epoch, continuous mountain-chains; so that the subdivision of the whole land into innumerable islands may be precluded.

If it be objected, that the maximum of elevation of land and depth of sea are probably not constant, nor the gathering together of all the land in certain parts, nor even perhaps the relative extent of land and water, I reply, that the arguments about to be adduced will be strengthened if, in these peculiarities of the surface, there be considerable deviations from the present type. If, for example, all other circumstances being the same, the land is at one time more divided into islands than at another, a greater uniformity of climate might be produced, the mean temperature remaining unaltered; or if, at another era, there were mountains higher than the Himalaya, these, more especially when placed in high latitudes, would cause a greater excess of cold. Or, if we suppose that at certain periods no chain of hills in the world rose beyond the height of 10,000 feet, a greater heat might then have prevailed than is compatible with the existence of mountains thrice that elevation.

Since I first proposed in 1830 to account for the more genial climates of former times, by showing that there is now an excess of land in polar regions, Mr. Hopkins made some important calculations to prove that, by reasoning on data, supplied by the isothermal maps of Dove, we may infer that a great alteration in climate would be brought about

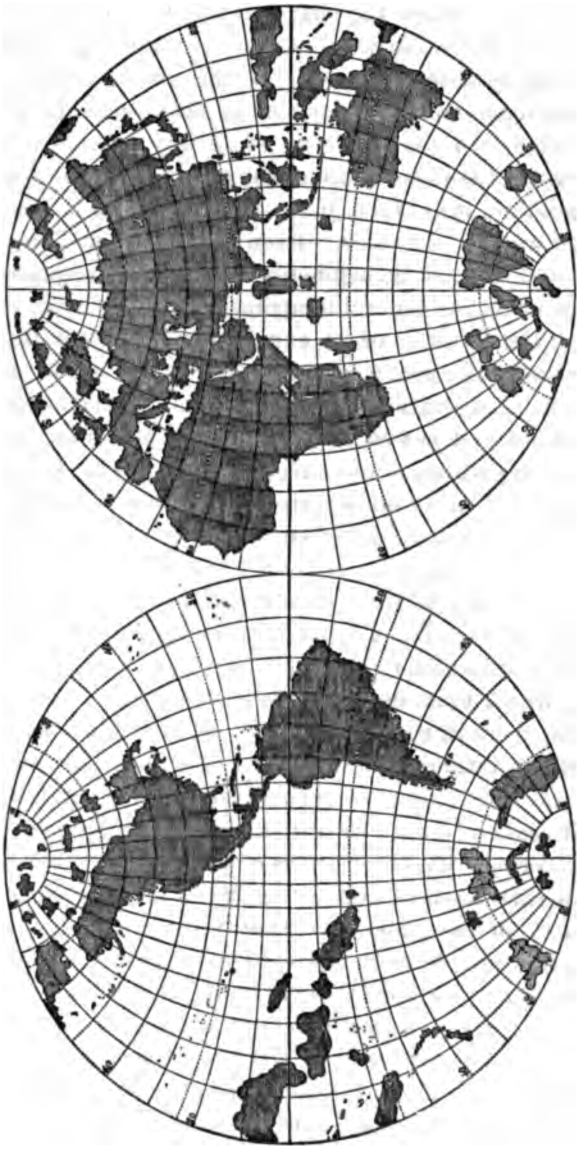
in the northern hemisphere by what every geologist must regard as slight alterations in geography. If, said he, we assume; 1st, the diversion of the Gulf-stream from its present northerly course; 2ndly, the depression of the existing land of Northern and Western Europe to the amount of no more than 500 feet; and 3rdly, a cold current from the North, sweeping over this submerged area, the effect would be, that both on Snowdon and the lower mountains of the West of Ireland the snow-line would descend to within 1,000 feet of the sea-level, and glaciers reach the sea.* Now everyone who is aware of the rising and sinking of land, of which we have proofs since the present species of animals and plants were in existence, or since the commencement of the Glacial epoch, will be prepared to concede that, without violating probability, we may imagine far more important changes to have occurred since the older Pliocene period than those above suggested. Even if we admit that the Glacial period began as far back as the close of the Newer Pliocene era, when perhaps 5 in 100 of the mollusca were of different species from those now living, we might still fairly speculate on the lapse of a period more than ten times as long since the older Pliocene deposits were formed, for in these more than half the shells belong to extinct species. We might reckon on a tenfold greater amount of geographical change as having occurred in an interval sufficient to allow of fluctuations in organic life on so much grander a scale. Even if changes in the position of land and sea are brought about as slowly as those now in progress, so as to be quite insensible to ordinary observation, we may still be prepared to believe that when we go back to the older Pliocene period, land between the arctic and antarctic circles and the pole may have been so much less in quantity as compared to what it now is, that, instead of being equal in area to the sea, it may only have been in the proportion of about 1 to 2½. But such a reduction of the quantity of land in high latitudes would be accompanied by an equivalent increase of land in temperate or tropical regions, unless we suppose the general surface of the earth's crust to have been less irregular than it is now—

* Quarterly Journ. Geol. Soc. 1852.

an hypothesis which we are not entitled to make. Consequently, whatever is lost to polar areas, where land gives rise to an augmentation of cold, would be gained in those lower latitudes, where it causes an increase of warmth. Therefore a more normal state of geography, or one in which the polar, temperate, and equatorial regions would each contain more nearly than they do now a proportion of one part land to two and a half parts sea, would bring back those genial climates which generally obtained in the past history of the world. It may perhaps be thought that the proofs lately brought to light of a rich vegetation having existed in Tertiary and even Cretaceous times within 10° of the pole, attest a greater extent of land in very high latitudes than is consistent with the theory above proposed. But the reader must bear in mind that we are always assuming that rather more than a fourth of the arctic area may have consisted of land, and this would be quite sufficient to produce the fossil plants hitherto discovered. It should also be remembered that we must not take for granted that the land from which arctic Tertiary strata derived their fossil plants was all above water at the same time, since even if it belongs to one era, such as the Miocene, there may have been great oscillations of level and conversion of sea into land and land into sea during the successive phases of the Miocene vegetation.

The accompanying map (fig. 13) may help the reader to imagine what would be the amount of change, if the geography of the globe were altered from its present exceptional state to what I consider a more normal condition of things. In this ideal map the excess of land is removed from the arctic and antarctic zones, and transferred to the tropical zone, which last, after this accession, contains only its normal quantity of land, or a proportion to the water of about 1 to 2½. The land thus shifted from the poles has not been placed at random in the tropics, but has been made to fill those oceanic spaces which are supposed to have been above water in Post-tertiary, or at least, in Newer Pliocene times, in accordance with Darwin's map of coral atolls. No doubt during such an amount of transposition of sea and

Fig. 13.



Ideal Map. in which the north and south polar lands are reduced to a normal quantity—1 land to 2½ sea; excess being shifted to areas of modern subsidence between the Tropics. (See p. 266.)

land in the polar and equatorial zones, there would be a corresponding amount of change in the outline of continents and islands in other regions; but those changes, if taking place within the same zone, might have but slight effect on the general climate of the globe or the average temperature of the atmosphere. So long as the conversion of sea into land or land into sea does not cause any alteration in the proportions of land to water in the same zones, a vast amount of fluctuation may take place without those zones being rendered warmer or colder. Even if the land and sea in the eastern and western hemispheres were to change places, this need not affect the general temperature of the earth's surface, although the transfer of an equal volume of land from the torrid zone to the arctic or antarctic regions would cause a prodigious refrigeration in all latitudes. I have therefore left the land and sea as they now are, that those variations in geography which would affect climate may be more easily recognised. In this same map it will be seen that the diminution of arctic and antarctic land would enable oceanic currents to flow more freely from high to low, and from low to high latitudes, so that there might always be much open sea at the poles. But I have not attempted to deal in this map with submarine geography or the shape of the sea-bottom, which must nevertheless often affect the course and direction of ocean currents, as well as that slow movement by which an interchange of waters of different temperature may be effected between the equatorial and polar seas.

Great depth of the sea as compared to the mean height of the land connected with the slowness of climatal changes.—I shall conclude this chapter by observing that if at any former period the climate of the globe was much warmer or colder than it is now, it would have a tendency to retain that higher or lower temperature for a succession of geological epochs. That tendency would usually be in favour of warmer climates, because these would be consistent with a normal state of geography; but if once abnormal conditions like the present prevailed, they would be persistent for an indefinite lapse of ages. The slowness of climatal change here alluded to would arise from the great depth of the sea as compared

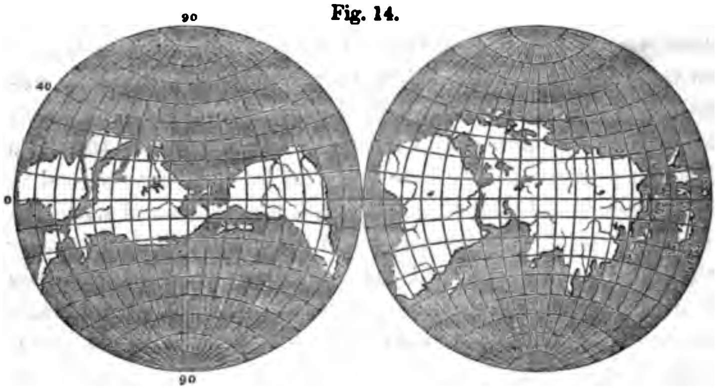
to the height of the land, and the consequent lapse of time required to alter the position of continents and great oceanic basins.

To one who contemplates the vast amount of geographical change which has occurred in Post-tertiary, and still more in Pliocene and Miocene times, it might at first sight appear that in the course of such a period as might correspond with the disappearance of one set of organic beings and the coming in of another, there would be an almost unlimited revolution in the outward form of the earth's crust. But such an opinion would not be in harmony with the facts which have come to our knowledge of late years in regard to the average height of the continents as contrasted with the enormous depth of the sea, both as inferred theoretically from observations on the tidal wave, and proved practically by deep-sea soundings. These have been very generally supposed to demonstrate that the average depth of the sea is 15,000 feet; while the mean height of the land is only 1,000 feet. Even if this estimate of the average depth of the ocean be an exaggeration, as some suspect, yet its excess over the height of the land is indisputable, for inequalities amounting to three or five miles, which on the land are so exceptional as to be confined to a few peaks and narrow ridges, occur in the abysses of the ocean continuously over wide areas. The effect, therefore, of vertical movements, equalling 1,000 feet in both directions, upward and downward, is to cause a vast transposition of land and sea in those areas which are now continental, and adjoining to which there is much sea not exceeding 1,000 feet in depth. But movements of equal amount would have no tendency to produce a sensible alteration in the Atlantic or Pacific oceans, or to cause the oceanic and continental areas to change places. Depressions of 1,000 feet would submerge large areas of the existing land, but fifteen times as much movement would be required to convert such land into an ocean of average depth, or to cause an ocean three miles deep to replace any one of the existing continents. It is quite essential to bear in mind this remarkable feature in the physical geography of the earth, when we are speculating on the cause of the permanence of a particular

climate, or distribution of heat or cold during a series of epochs. According to the doctrine of chances, it would not often happen that even one of the polar regions would con-

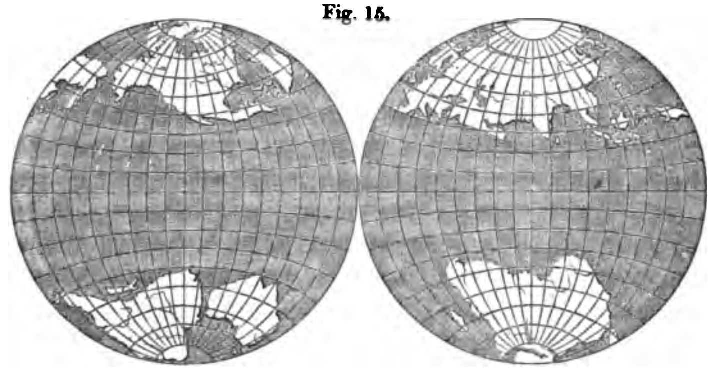
MAPS showing the position of LAND and SEA which might produce the Extremes of HEAT and COLD in the Climates of the GLOBE.

Fig. 14.



Extreme of Heat.

Fig. 15.



Extreme of Cold.

OBSERVATIONS.—These maps are intended to show that continents and islands having the same shape and relative dimensions as those now existing, might be placed so as to occupy either the equatorial or polar regions.

In fig. 14, scarcely any of the land extends from the Equator towards the poles beyond the 30th parallel of latitude; and in fig 15, a very small proportion of it extends from the poles towards the Equator beyond the 40th parallel of latitude.

tain so much land as each of them does at present, but great indeed would be the chances against the simultaneous preponderance of such an abnormal quantity of land, both in arctic and antarctic latitudes.

The annexed maps will enable the reader to understand the manner in which land, having the same proportion to the sea of 1 to 2½ as it now has, might be collected together in equatorial or polar regions. Such extremes may never have occurred, but we may safely conclude that there may sometimes have been an approximation to them in the course of those ages to which our geological records refer. A glance at these maps will make it evident that in the present state of the globe we are much nearer to the winter than to the summer of the 'Annus Magnus,' or great cycle of terrestrial climate.

CHAPTER XIII.

VICISSITUDES OF CLIMATE, HOW FAR INFLUENCED BY ASTRONOMICAL CHANGES.

THE PRECESSION OF THE EQUINOXES, AND VARIATIONS IN THE EXCENTRICITY OF THE EARTH'S ORBIT, CONSIDERED AS AFFECTING CLIMATE—SIR JOHN HERSCHEL'S VIEWS UPON THIS SUBJECT—LATER THEORIES AS TO THE EFFECT OF ASTRONOMICAL CAUSES—CLIMATES OF THE SUCCESSIVE PHASES OF PRECESSION—PREDOMINATING EFFECT OF GEOGRAPHICAL CAUSES ON THE PRESENT CLIMATE OF THE EARTH—HOW FAR WE MAY SPECULATE ON A PROBABLE DATE FOR THE GLACIAL PERIOD—EVAPORATION OF ICE AND SNOW IN A DRY WAY—RADIATION OF HEAT IMPEDED BY A COVERING OF SNOW—ABSENCE OF RECURRENT GLACIAL PERIODS IN THE EARLIER FORMATIONS—VARIATION IN THE OBLIQUITY OF THE ECLIPTIC—SUPPOSED VARIATIONS IN THE TEMPERATURE OF SPACE—SUPPOSED DIMINUTION OF THE EARTH'S PRIMITIVE HEAT.

In the last chapter we were chiefly occupied in considering how far changes in physical geography or in the position of land and sea may account for those variations of climate to which geology bears testimony. I endeavoured to show that this class of causes must always have exerted a dominant influence; and we may now consider how far those variations in the relative position of our planet to the sun and the other heavenly bodies which astronomy reveals to us, may have co-operated with geographical conditions in bringing about fluctuations of temperature on the globe in former ages.

The influence of astronomical changes on climate considered by Sir J. Herschel.—Sir John Herschel in 1832 * entertained the question whether there are any astronomical causes which might offer a possible explanation of the difference between the actual temperature of the earth's surface and the climates which appear formerly to have prevailed. 'Geometers,' he observed, 'had demonstrated the absolute invariability of the earth's mean distance from the sun, whence it would seem to follow that the mean annual supply of light

* Trans. Geol. Soc. 2nd series, vol. iii.

and heat would be alike invariable. This, however, is not exactly true: the total quantity of heat received in one revolution is inversely proportional to the minor axis;' still, as the extreme amount of difference in the quantity of heat annually received, owing to such change in the minor axis, can never by possibility exceed the whole supply in a ratio of more than 1,003 to 1,000, it may, he says, be neglected in our geological speculations.

But there is another way in which changes in the excentricity of the orbit affect climate. Climate depends, not merely on the absolute amount of heat, but on the manner in which it is distributed through different parts of the year, especially in the polar and circumpolar zones of the earth. There are in fact three astronomical causes which by their combination with each other and with varying geographical conditions may exert a sensible influence on the earth's climate. These are the phenomena known as the excentricity of the earth's orbit, the precession of the equinoxes, and the revolution of the apsides.

It is well known that the orbit of our earth round the sun is not circular, but elliptical, the sun occupying one of the foci of the ellipse (see figs. 16 to 19, p. 276), so that the earth in its yearly course now approaches in December, or our northern winter, three millions of miles nearer the sun than it does in June (see fig. 16), the mean distance of the earth from the sun being 91,400,000 miles.* The extreme point of approach is called *perihelion*, the extreme point of distance *aphelion*.

The difference of three millions of miles which now expresses the excentricity of the earth's orbit is not constant: at present the orbit is becoming every year more circular, at a very slow and somewhat irregular rate, and it will become in 23,980 years after A. D. 1800 nearly as circular as it can ever be, or will approach a minimum excentricity, when the difference between perihelion and aphelion will only slightly exceed half a million of miles, or one-sixth of the present; after this the excentricity will again increase at the same slow rate. The movement will not be constant in one direction, but will

* Herschel's Astronomy, art. 368.

vary within fixed limits, the extreme range of difference which it can ever attain amounting to fourteen millions of miles, as was shown by Lagrange towards the end of the last century, and more exactly by Leverrier in 1839. The cause of these perturbations is the attraction of the nearest and largest planets, Jupiter and Saturn playing the principal part, and Venus and Mars also exerting a sensible influence.

Whatever be the ellipticity of the earth's orbit, says Sir J. Herschel, the two hemispheres must receive equal absolute quantities of light and heat per annum, the proximity of the sun in perigee or its distance in apogee exactly compensating the effect of its swifter or slower motion.* But the same writer, in 1858, alluding to some speculations of Reynauld, speaks of the marked effects on climate which great variations in excentricity might produce, causing the characters of the seasons in the two hemispheres to be strongly contrasted. So long as the position of the earth's perihelion remained the same as now 'we should have in the northern a short but very mild winter, with a long but very cool summer —i.e., an approach to perpetual spring; while the southern hemisphere would be inconvenienced, and might be rendered uninhabitable by the fierce extremes caused by concentrating half the annual supply of heat into a summer of very short duration, and spreading the other half over a long dreary winter, sharpened to an intolerable intensity of frost when at its climax, by the much greater remoteness of the sun;'† and he goes on to observe that, in consequence of the precession of the equinoxes, combined with the secular movement of the aphelion, the state of the northern and southern hemispheres here alluded to, would in the course of about 11,000 years be reversed, and as such alternations of climate must in the immense periods of the past which the geologist contemplates have happened, not once only, but

* This follows, observes Herschel, from a very simple theorem, which may be thus stated: 'The amount of heat received by the earth from the sun, while describing any part of its orbit, is proportional to the angle described round the sun's centre.' So that if the orbit be divided into two portions by a line drawn *in any direction* through the sun's centre, the heat received in describing the two unequal segments of the ellipse so produced will be equal.—Geol. Trans. vol. iii. part ii. p. 298; second series.

† Herschel's Astronomy, art. 368 c.

thousands of times, 'it is not impossible,' he adds, 'that some of the indications of widely different climates in former times may be referable, in part at least, to this cause.'

The precession of the equinoxes here alluded to is due, as is well known, to the attraction of the sun and moon on the protuberant matter at the earth's equator, and its effect is to cause the different seasons of the northern and southern hemisphere to coincide successively with all the points through which the earth passes in its orbit round the sun. This great cycle of change would be gone through in 25,868 years were it not shortened by being combined with another movement called the revolution of the apsides, or, in the passage above cited from Herschel, the 'motion of the aphelion.' This last consists of a gradual change in the direction of the major axis of the earth's orbit due to the same disturbing forces which cause the ellipticity of the orbit to vary, namely, the attraction of the larger and nearer planets. The result of the combination of these two causes of perturbation is that in about 10,500 years the present astronomical state of things will be reversed, and in 21,000 years the seasons will have made a complete revolution, so as again to coincide with the same point in the orbit as at present. For example, our winter in the northern hemisphere occurs at present in perihelion (see fig. 16), our pole being turned away from the sun when the earth is nearest to the sun. But in consequence of the precession of the equinoxes and the revolution of the apsides, our winter will have passed in 5,250 years through about one quarter of the orbit, and will occur at *a*, fig. 17. In another 5,250 years it will have reached aphelion (see fig. 18), and our long northern winter nights will coincide with the greatest distance of the earth from the sun. In another 5,250 years it will have reached *a*, fig. 19; and, finally, 21,000 years from the time at which it started, the earth will again arrive at that point in which our winter and the antarctic summer coincide with perihelion (fig. 16).

If the orbit were circular, and our planet always equidistant from the sun, this precession of the equinoxes would have no effect upon climate; but the orbit being elliptical, it

is easy to see that, astronomically speaking, the northern winter in perihelion, as shown in fig. 16, ought to be less rigorous than winter of the same hemisphere in aphelion, as

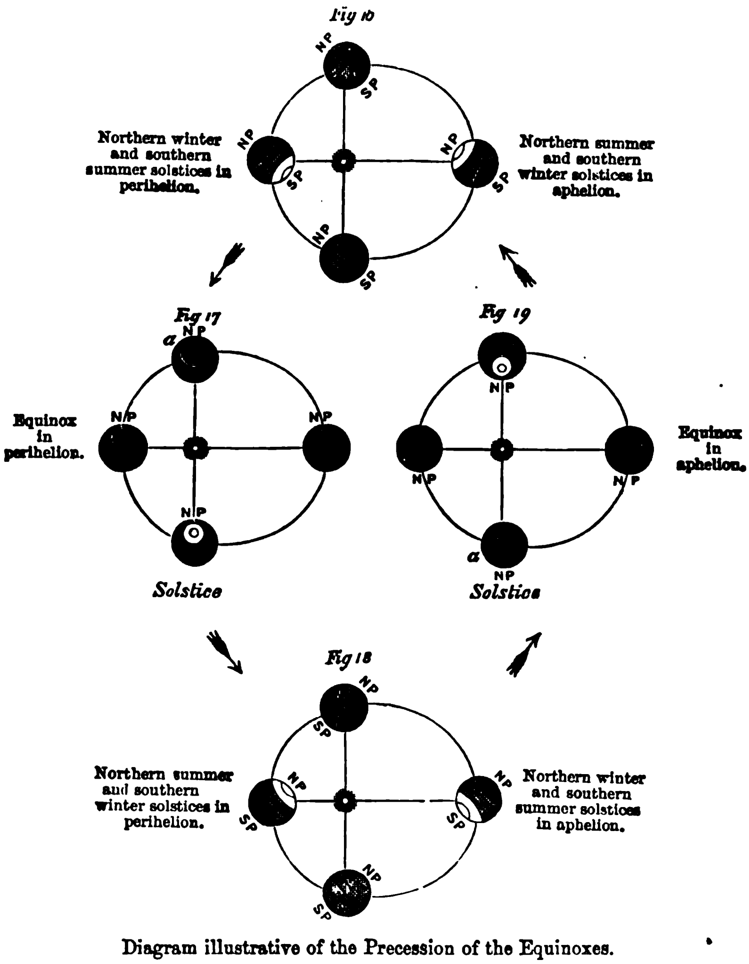


Diagram illustrative of the Precession of the Equinoxes.

In order to give a clear idea of the ellipse, it has been drawn as though the reader looked down upon it directly from above, while the figures of the globe are drawn as they would appear if placed rather more on a level with the eye.

The black patches represent winter; the white patches, summer.

in fig. 18, because the distance of the earth from the sun in the first case is less.

M. Adhémar, in a work entitled 'Les Révolutions de la

Mer,' published in 1840, suggested that a sensible effect has already resulted from the deviation which has occurred since the year 1248, of the position of the perihelion from the time of the winter solstice in the north. By this movement the nearest approach to the sun now occurs eleven days after the shortest day. M. Venetz had previously pointed out, as an historical fact, that before the tenth century the Swiss glaciers were larger than they are now, and that then, after retreating for four centuries, they advanced again and have been slowly reacquiring their former dimensions. In other words, at that period when the sun was nearest the earth in midwinter, or for two centuries before and two after 1248, there was the greatest melting of ice in the northern hemisphere. It may be questioned whether this slight astronomical change, which could hardly produce more than a difference of half a degree Fahrenheit between the cold of the present winter and that of 1248, would be appreciable in the course of 600 years; but the observation may help the reader to understand in what direction the precession of the equinoxes, if capable of producing a sensible change, would now be affecting climate.

It is obvious that this effect would be intensified whenever the ellipticity of the orbit is increased, for the difference of distance between aphelion and perihelion is now only 3,000,000 miles, but it would be at some periods as much as 14,000,000, causing, as Mr. Croll has pointed out, a difference of heat received at the two points amounting to about one-fifth of the entire heat received from the sun, because the amount of such heat varies inversely as the squares of the distance.*

Suggestions by Mr. Croll as to the effects of excentricity on climate.—Upon this difference of heat Mr. Croll has founded a theory which attempts to account for former changes of climate by the tendency which a maximum excentricity would have to exaggerate the cold in that hemisphere in which winter occurred in aphelion.† In consequence, he

* See Herschel's Astronomy, art. 368 *a*.

† Croll on the physical cause of change of climates during geological epochs Phil. Mag., August 1864.

says, of the lowering of the temperature by one-fifth in that hemisphere in which winter occurs when the earth is farthest from the sun, all the moisture precipitated from the air in high latitudes would fall in the form of snow instead of rain; and the heat in the same hemisphere of summer in perihelion, although one-fifth greater than what we now experience, would be insufficient to remove the accumulation of winter snow. The direct power of the sun's rays would be greatly intensified when the sky was cloudless, but the melting of so much ice would, he thinks, in a great measure neutralise their force by giving rise to fogs and an overcast sky. This point I shall discuss more fully in the sequel (pp. 280 and 289), but it appears to me that he is here obliged to make an assumption for which we have no certain data—namely, that the intensely blazing sun in a clear sky which would first melt the ice would afterwards be sufficiently overcome by fog to check and almost prevent further melting, in spite of the continued supply of excessive heat during the summer. In accordance with this view he maintains that while one hemisphere during this maximum excentricity would be enduring the extreme cold of a lengthened winter, and having its summer heat chilled by the melting of ice, the other hemisphere would be enjoying simultaneously the perpetual spring alluded to by Herschel; the polar winter occurring in perihelion, when the temperature was one-fifth greater than at present, and there being no accumulation of snow beyond what the sun's rays could dissipate during the course of the year.

He has also endeavoured to show that the vast accumulation of ice which would alternately take place at each pole during that phase of precession in which winter would occur when the planet was farthest from the sun, would so derange the earth's centre of gravity as to draw the ocean towards that pole, and cause the submergence of part of the land. M. Adhémar, in 1843, had already endeavoured to account for certain geological phenomena by a coincidence of the winter solstice with aphelion, but without connecting them, as Mr. Croll has done, with that greater excentricity of the earth's orbit, which must occasionally in the course of ages vastly exaggerate the effects alluded to. Although the deficiency

of our data is such that we cannot yet decide to what extent this excess of ice would act as a disturbing cause, yet, as there can be no doubt that it must have given rise at certain periods to some difference in the ocean's level, we are greatly indebted to those scientific writers who have called attention to a *vera causa* hitherto neglected.

In the memoir above alluded to, little or no influence is ascribed by Mr. Croll to abnormal geographical conditions, such as now prevail; and which, according to the principles explained in the last chapter, I consider by far the most influential in the production of great cold. Granting that under favourable geographical circumstances the greatest accumulation of snow would always take place at that pole where midwinter happened to occur in aphelion, I also think it probable that, be the amount of excentricity great or small, there would be no increase of cold from year to year, so often as the distribution of land and sea is not exceptional, or whenever a normal condition of things obtains as expressed in the ideal map, fig. 13, p. 267. Moreover, it appears to me almost certain, that whenever a deep ocean prevailed at both poles, the astronomical causes alone would be powerless for the storing up of ice, and during extreme excentricity, the minor axis of the ellipse being shortened, the total quantity of heat received from the sun would be slightly in excess of the present,* and so far as it went would be in an opposite direction to that which would bring about glacial periods. In extreme excentricity there is at least as great an excess of heat in summer in perihelion as there is loss in winter in aphelion, so that we cannot suppose the total amount of snow lying on the ground to be increased unless there should intervene some cause to mitigate the extreme heat of summer. This has been supposed by Mr. Croll to be the case when he says as above that the first action of the summer sun would be to raise a fog which would effectually prevent the sun's rays from reaching the earth. But in the papers in which he advances this supposition he does not state the reasons why anything like a

* See p. 273; and Meech, Intensity of the Sun's Heat and Light, Smithsonian Contributions, 1857.

universal arctic fog should be produced. The heating effect of the sun, for the first part of the summer at least, is continually increasing, and consequently the power of the heated air to absorb aqueous vapour is also augmenting; it is therefore not easy to see how fogs could arise, except where an abnormal quantity of high snow-covered land was collected around the pole.

Climates of the successive phases of precession with increased excentricity.—But there is another circumstance tending to the equalisation of the heat, which must be borne in mind, lest we should exaggerate the effects of excentricity on climate, even when intensified by such abnormal conditions of the earth's geography as now prevail. We ought not to divide the 21,000 years before spoken of as constituting the cycle caused by precession and the revolution of the apsides into two equal parts, as M. Adhémar and others have proposed, one of which in a given hemisphere should be a cold period when the winters coincide with aphelion, and the other a warm period when the winters coincide with perihelion. For it must be borne in mind that there will be no sharply defined line between the warmest and coldest periods, but a gradual transition between these extremes. We shall get a clearer notion therefore of the varying climatal conditions if we divide the cycle of precession into four quarters (as in figs. 16 to 19, p. 276), in the first of which there is an accumulation of ice in the southern hemisphere, because of the coincidence of the long antarctic night and short days with the greatest distance of the planet from the sun, or, in other words, because the southern winter happens when the earth is at or near aphelion, and granting, for the sake of argument, Mr. Croll's hypothesis of the accumulation of fogs and clouds, the more intense heat of 5,250 summers in perihelion is supposed to be unequal to the task of melting the snows of an equal number of winters. Then follows the next quarter, when the vernal equinox occurs at the least distance from the sun, and an equable climate is produced, whatever be the amount of excentricity; for the 5,250 winters and summers will be of nearly equal duration, and the summer and winter distances from the sun also equal,

both of which causes will combine to make these seasons vary but little from the mean, and will cause a reduction of the snow and ice accumulated in the preceding quarter. In the third quarter the cold of all the winters is neutralised by proximity to the sun, while the heat of the summers is in like manner moderated by the earth's distance from it, so that here again an equable climate is produced. In the fourth quarter, the autumnal equinox falling at or near aphelion, the same effects will be produced as in the second quarter, and there will be no great exaggeration of heat or cold, like that which must take place in the first quarter. This first quarter therefore is the only one in which, under favourable geographical conditions like the present, an accumulation of ice and snow will take place at whichever pole has its winter in aphelion.

Present effect of geographical causes on the climate of the earth.—A good illustration is afforded of the preponderating influence of geographical causes by the result of Dove's observations on the present mean temperature of the whole surface of the globe in perihelion as contrasted with its temperature in aphelion.

The present excentricity of the earth's orbit amounts, as before stated (p. 273), to no more than a million and a half of miles in opposite directions from its mean distance from the sun, which is ninety-one millions. The difference of distance of the earth from the sun, in aphelion and perihelion, is therefore no less than one-thirtieth of the mean distance, and the planet therefore ought to be colder at the one time and hotter at the other, not merely by one-thirtieth of the heat received from the sun, but by about one-fifteenth, because the heat varies inversely as the squares of the distance. Yet, as if in violation of this law, when the temperatures of all places north and south of the line are reduced to an average, it is found that the surface of the whole planet is actually warmer in June than in December, i.e. in aphelion than in perihelion. This result, which in an astronomical point of view appears so paradoxical, is explained in a satisfactory manner when we take into consideration that the effect of land under sunshine is to throw heat into the general atmosphere, and

so distribute it by the carrying power of the air over the whole earth.* For the great extent of land which exists between the equator and the fiftieth degree of north latitude, is exposed to the sun's rays during a long summer, whereas the extent of ocean in corresponding latitudes in the southern hemisphere prevents any similar generation of heat during summer, notwithstanding that here, according to Herschel's estimate, the power of the sun is greater by 23° F. when the planet is in perihelion.

Another illustration of the counteracting effect of geographical causes is afforded by the extreme climates of Canada and other parts of North America, as well as of certain parts of Siberia and China, as contrasted with the more equable climates of the southern hemisphere. A very different result might have been looked for if the ascendency of astronomical causes were complete; for in that hemisphere where winter coincides with the greatest and summer with the least distance from the sun, the seasons would have been most contrasted were it not that the preponderance of sea as compared to land produces an equable or what is called an 'insular' climate.

The fact that the cold is now greater throughout a large part of the southern hemisphere would seem at first sight almost to demonstrate the truth of the theory that the coincidence of the winter solstice with aphelion exerts a powerful refrigerating effect. But the difference of about 10° F. in temperate latitudes in the southern hemisphere is shown by Dove's tables to be due to a deficiency of land, which is in excess in corresponding latitudes of the northern hemisphere. Without denying that the astronomical cause alluded to may exercise some influence, it is obviously insignificant as contrasted with the power of geographical conditions. Sir John Herschel, indeed, computes on theoretical grounds that there ought to be a difference of 23° F. when two places are compared at the same season and in the same latitudes on opposite sides of the equator; that is to say, the summer coinciding with perihelion ought to have a temperature of 11½° higher, and the winter in aphelion a temperature lower

* Herschel's Astronomy, 1864, p. 236, art. 376.

by the same amount, than the same seasons in the opposite hemisphere, where these astronomical conditions are reversed. The results of observation are not in harmony with this theory, the difference really indicated by the thermometer being only half that which is required by theory. Yet there are some limited areas where, according to Herschel, the excentricity makes itself felt. The heat, he says, in the interior of Australia is greater than in the deserts of North Africa in corresponding latitudes; and he has himself observed the temperature of the surface soil in South Africa to reach 159° F., which is higher than it rises in our hemisphere, where summer does not coincide with perihelion.* The question, however, of the measurement of heat depends upon an arbitrary assumption as to the temperature of space, or the degrees of heat which our thermometers would indicate if they could be placed at some point beyond our atmosphere and shaded from the sun. As it is impossible to test this experimentally, and different physicists of the highest eminence are not agreed even as to the conditions of the problem, I shall not enter into calculations, the accuracy of which cannot at present be depended upon.

The simple fact that totally different climates exist now in the same hemisphere and under the same latitude would alone suffice to prove that their occurrence cannot be exclusively due to astronomical influence. The reader has only to refer to p. 243 to see that the climates of South Georgia and Tierra del Fuego are at present so different that the former might be supposed to belong to a glacial period, while the latter, by its flowers and humming-birds in the winter, and the genera of marine mollusca in the adjoining sea, might indicate to the traveller, as well as to some future geologist, such a temperature as has been spoken of as perpetual spring. This contrast is due to geographical causes, which if reversed, so that Tierra del Fuego became the oceanic island, would reverse the climates also. Mr. Darwin, in the last edition of his 'Origin of Species,' † has inclined towards adopting Mr. Croll's theory of alternate glaciation and perpetual spring in the opposite hemispheres, on the ground that

* Herschel's Astronomy, 1864, art. 369, *note*. † Pp. 450-461.

it would account for some anomalies in the distribution of animals and plants, by affording a refuge for tropical life during a period of extreme cold. But it appears to me that such cases as the one just mentioned of South Georgia and Tierra del Fuego are a warning against assuming that glaciation must be universal in all corresponding latitudes of the same hemisphere, and that until we know what climate the countries now inhabited by tropical animals and plants were enjoying in glacial times it is premature to contend with imaginary difficulties as to the survival of forms which would have been extinguished if the snow and ice had been universal down to latitude 55°, even over one hemisphere at a time.

How far we may speculate on a probable date for the Glacial Period.—From what I have now said in this and the preceding chapter, it will be seen that I consider the former changes of climate and the quantity of ice now stored up in polar latitudes to have been governed chiefly by geographical conditions. Nevertheless, since I also consider it probable that a much larger excentricity of the earth's orbit if combined with the present excess of polar land would produce an exaggeration of cold in both hemispheres, it becomes a matter of no small interest to ascertain the dates of those variations in the excentricity of the orbit which may throw light on the times when the cold first came on, when it reached its height, and when it was succeeded by the great thaw which reduced the ice to its present limits.

On my applying to the Astronomer Royal, Mr. Airy, for assistance in this enquiry, he suggested to Mr. Stone, of the Greenwich Observatory, to make some of the required calculations; and that eminent mathematician undertook, by the use of Leverrier's formula, to determine when the last high excentricity occurred. He found that it happened 210,065 years ago,* and that no other excentricity approaching to this in amount could be obtained by going back half a million of years from the present era. The difference between the greatest and least distances, at the time alluded to by Mr. Stone, was about eleven millions of miles, while at the

* Letter to the Author, May 15, 1865; and see Phil. Mag., June 1865.

maximum the difference would be about fourteen millions. At present it is about three millions, so that the proportions of distance are expressed by the figures 3–11–14. Hence, as Mr. Stone observes, 'whatever climatic changes may have

TABLE SHOWING the variations in the excentricity of the earth's orbit for a million years before A.D. 1800, and some of the climatal effects of such variations.

	1	2	3	4
	Number of years before A.D. 1800	Excentricity of orbit	Difference of distance in millions of miles	Number of winter days in excess
	0,	·0168	3	8·1
	50,000	·0131	2¼	6·3
A	100,000	·0473	8½	23
	150,000	·0332	6	16·1
B a	200,000	·0567	10¼	27·7
B b	210,000	·0575	10½	27·8
	250,000	·0258	4½	12·5
	300,000	·0424	7¾	20·6
	350,000	·0195	3½	9 5
	400,000	·0170	3	8·2
	450,000	·0308	5½	15
	500,000	·0388	7	18·8
	550,000	·0166	3	8
	600,000	·0417	7½	20·3
	650,000	·0226	4	11
	700,000	·0220	4	10·2
C a	750,000	·0575	10½	27·8
C b	800,000	·0132	2¼	6·4
C c	850,000	·0747	13½	36·4
	900,000	·0102	1¼	4·9
D	950,000	·0517	9¼	25·1
	1,000,000	·0151	2¾	7·3

EXPLANATION OF THE TABLE.

Column 1. Division of a million years preceding 1800 into twenty equal parts.

Column 2, computed by Mr. James Croll by aid of Leverrier's formula, gives the excentricity of the earth's orbit in parts of a unit equal to the mean distance or half the longer diameter of the ellipse.

Column 3, which together with the following column has been computed by Mr. John Carrick Moore, gives in millions of miles the difference between the greatest and least distances of the earth from the sun, during the excentricities given in column 2.

Column 4 gives the number of days by which winter occurring in aphelion is longer than the summer in perihelion.

taken place at some distant period through the existence of the absolute maximum of excentricity, corresponding and but slightly inferior changes must have taken place about 210,000 years before the beginning of the present century.'

Mr. Croll, following up the series of calculations begun by

Mr. Stone, rendered a great service to science by accomplishing the laborious task of computing the changes of excentricity for a million years preceding and a million following A.D. 1800. I have taken the two first columns of the annexed table from his memoir, and the results given in the other two columns have been computed by my friend Mr. John Carrick Moore, who by his mathematical and geological knowledge has rendered me invaluable assistance in all these enquiries on changes of climate. It appears to me that the third and fourth columns will help the reader more clearly to appreciate the variations in temperature which are indicated by the figures in the second column. A glance at this table will show that there are four periods in the course of the last million of years, namely, those marked A, B, C, D, in which there has been a large excentricity. For in A it was nearly three times as great as it is at present; in B three and a half times; in C we find two periods, one three and a half and the other four and a half times as great, with an intervening small excentricity; and lastly, in the period D, more than three times the present excentricity.

The attempt to assign a chronological value to any of our geological periods except the latest must, in the present state of science, be hopeless. Nevertheless, independently of all astronomical considerations, it must, I think, be conceded that the period required for the coming on of the greatest cold, and for its duration when most intense, and the oscillations to which it was subject (p. 192), as well as the retreat of the glaciers and the 'great thaw' or disappearance of snow from many mountain-chains where the snow was once perpetual, required not tens but hundreds of thousands of years. Less time would not suffice for the changes in physical geography and organic life of which we have evidence. To a geologist, therefore, it would not appear startling that the greatest cold should be supposed to have coincided with the period B, 200,000 years ago, although this date must be considered as very conjectural, and one which may be as likely to err in deficiency of time as in excess. I formerly speculated * on the more remote periods C and D for

* Principles, 10th ed., 1867.

the Glacial Period, but upon reconsideration it appears to me that geographical conditions are so paramount that we must not go further back in time than we are able fairly to assume that the principal geographical features of the continents and oceanic basins approximated to those now prevailing. If, for example, the Alps and Jura were as high or perhaps higher than now, we may suppose that whenever the winter of the northern hemisphere coincided with aphelion during a period of high excentricity, the Alpine glaciers would have been far in excess of what they are now, whereas if we go back 800,000 or 1,000,000 years to C or D, in order to reach a somewhat higher excentricity, we know not how far the geography may have coincided with that now established, so as to allow of the excentricity augmenting or diminishing the glaciation of the poles. There may, for example, have been no Gulf-stream, the Sahara may have been submerged, and a great many other areas may have been so differently circumstanced that it would be rash to reason upon the state of climate, whether general or local.

We have no right to assume that the distance of our planet from the sun during part of the year would cause so much cold as to counterbalance the heat resulting from greater proximity at another period of the year, unless the distribution of land and sea was unfavourable to that interchange of warmth and cold between polar and equatorial regions on which the very existence of ice and snow on the earth depends. If I am right in believing that the present geographical circumstances are exceptional, then the climates of the pole will be equally exceptional, and will have been so during the whole period when the continents and oceans gradually assumed their present form. This form is favourable, as we now see, to the simultaneous glaciation of both polar regions, and we cannot doubt that the local excess of ice and snow will vary in each hemisphere in proportion as winter coincides with aphelion. It is therefore natural that we should find periods in the Newer Pliocene and Post-Tertiary deserving the appellation of 'glacial,' while a wider geological survey might show us few or no monuments of such glaciation, even in the shape of erratics, although if glacial conditions

had prevailed they ought to have abounded between the thirtieth and fiftieth parallels of latitude in formations requiring such vast periods for their accumulation as the Cretaceous, Neocomian, and Carboniferous.

With regard to the more recent excentricities of the periods A and B, when a predominance of land in high latitudes may more safely be assumed, the fact which would seem to me most favourable to the connection of a large excentricity with an excess of cold is the following:

By referring to the map of Isothermal Lines (fig. 9, p. 240), the reader will see that the mean annual isothermals of 14°, 23°, 32°, 41°, and 50° Fahr., are all of them in their range from Europe to North America deflected from 13° to 18° of latitude in a southerly direction in their passage from east to west. The late Edward Forbes has also shown in one of his maps,* that the living arctic fauna extends in like manner 10° farther south on the west side of the Atlantic than on the east side. This difference, as before pointed out (p. 239), is dependent on purely geographical and not on astronomical causes: the direction of the Gulf-stream from south-west to north-east—the cold polar current flowing south along the east coast of North America—the extension of the land of the latter continent continuously towards the pole in the same latitudes as those where there is open sea to the north of Europe, are sufficient to explain the present course of the isothermals; and if the cold were now augmented by the coming on of a large excentricity, the isothermals alluded to would exhibit the same curves, their position being shifted farther south because the new refrigerating influence would operate equally on the eastern and western hemisphere. If the effect would not be exactly equal on both sides of the Atlantic, it would be in favour of greater curves in the direction in which they now bend, because the increase of snow and ice would be greatest on the side where there is most land in very high latitudes.

Now we find that in the Glacial Period all signs of glaciation, such as erratic blocks, scored surfaces of rock, striated boulders, and deposits filled with arctic species of marine

* Memoirs of the Survey of Great Britain, vol. i. plate vii.

shells, are to be seen in full force on the North American continent ten or more degrees farther south than in Europe. If we could assume, therefore, that geographical conditions had been constant, these phenomena would be in favour of our attributing the greater intensity of cold in the Glacial Period to a maximum excentricity. Our full reliance, however, on this line of reasoning is somewhat weakened when we reflect that a moderate amount of geographical change in a very high latitude—such as the addition of some islands near the pole, or the increased height of some of the land now existing between latitudes 70° and 80° N.—might exaggerate the cold both of the eastern and western hemispheres, acting alike on northern Europe and North America. We know, as a positive fact, that geographical changes have taken place in the height and position of land since the commencement of the Glacial Period, although we cannot affirm that when the cold was at its height there was a greater proportion of land in high latitudes than at present. If at that time it were in excess, we are more certain that the change alluded to would intensify the cold than we are that a change of excentricity would have the same effect; for the last-mentioned conclusion depends upon the soundness of the hypothesis that, in spite of the annual supply of solar heat being always equal, the more intense heat of summer cannot overcome the increased winter's cold whenever the latter gives rise to a much greater snow-fall.

Evaporation of ice and snow.—Now observations on the Swiss glaciers have shown to what an extent those rivers of ice are often lowered by evaporation, or by the passage of the ice into a gaseous form, without its having passed through the intermediate fluid condition. When certain dry winds blow, the snow wastes away like camphor without melting; and as we see the average number of inches of rainfall to diminish constantly, though very irregularly, as we pass from the equator to the pole, so we may reckon on a diminution of the quantity of snow and the prevalence near the pole of a dry air, especially if there be snow-covered lands farther south intercepting aërial currents blowing

from warmer regions, and causing them to part with their moisture in the form of snow.

M. Darwin, during his visit to Central Chili, was informed that during one dry and very long summer all the snow disappeared from Aconcagua, although it attains the height of 23,000 feet. It is probable, he adds, that much of the snow at these great heights is evaporated rather than thawed.*

In the Himalayas, where some of the mountain-peaks attain the height of 29,000 feet, the snow-line on the southern side of the chain occurs at 13,000, and on the northern at 16,000 feet, or, according to some authorities, even at 18,000. 'For the moist winds of the south-west monsoon,' says Herschel, 'deposit their snow almost wholly on the southern side, while the northern is exposed to the evaporation of one of the driest regions of the globe. like manner, when colder winds from the temperate zone first meet the frozen air of the arctic or antarctic regions, they will part with their moisture, so that the snow will increase on the outer margin of the antarctic continent rather than in the interior. As it is well known that great falls of snow take place chiefly when the thermometer is about 32° F., and that little, if any, ever falls when the temperature is much lower, it would certainly be rash to assume that intense cold near the pole during the aphelion, when the excentricity is very large, tends to generate more snow than the dry atmosphere can absorb.

Much snow was seen by Rink to have vanished from the surface of Greenland in the latter months of autumn, so that lines of erratic blocks were disclosed to view. In like manner, Ross and Hooker observed blocks of stone on the snows of Victoria Land—facts which would be inexplicable if much of the snow which falls annually were not removed from the surface by evaporation and liquefaction in high latitudes. Mr. Alexander Agassiz, when living on the shores of Lake Superior, describes the thermometer as being at 5° below zero for four months in the year, and says that the average annual snowfall of fifteen years was seventy-two feet. Yet the snow never lay more than six feet thick on the ground, and disappeared completely in the summer, the snow being

* Darwin, Journal of the Beagle, 1845, p. 245.

chiefly got rid of by evaporation like camphor. He also mentions that the ground beneath the snow never froze, and upon this point it is well to bear in mind that a covering of snow extending over a large area and enduring for a long time must have the effect of preventing loss by radiation, snow being a very bad conductor of heat.

It is observed in Canada and New England that parts of a meadow which are laid bare in winter by the wind having blown away its snow are often frozen for a depth of two feet or more, so that when spring returns, this portion of the surface remains brown and barren, while the rest of the field, having retained its heat during winter in consequence of the covering of snow, is green and clothed with a rapidly growing vegetation. Dr. Hooker found in like manner that after the melting of the snow on the Himalaya the warmth of the soil was far above the mean temperature of the region, owing to the same cause. In this way there may be some compensation, the excess of heat absorbed by the land during a short but hot summer being less freely parted with in winter owing to the snow. This loss by radiation during a protracted winter is only one of many elements as yet undetermined which complicate the problem on which we are speculating.

Absence of recurrent Glacial epochs in the earlier formations.— If we now turn from the physical difficulties raised by the astronomical theory to the question of palæontological evidence, we find that if the sketch which we have given in the tenth and eleventh chapters of the former states of climate revealed to us by palæontological research be an approximation to the truth, glacial periods have not been perpetually recurring in the northern temperate zone, as they ought to have done were a large excentricity alone sufficient, apart from the co-operation of all other causes, to intensify the cold of high latitudes. It was shown that the flora and fauna do not exhibit signs of violent revolutions from hot to cold and from cold to hot periods. On the contrary, the continuity of forms, particularly in the class of reptiles, from the Carboniferous to the Cretaceous Period, is opposed to the intercalation of glacial epochs corresponding in importance

to that of Post-Pliocene date. The Carboniferous Period must have endured for a lapse of centuries sufficient to allow several great cycles of excentricity to be gone through. Yet there must have been nevertheless a long suspension in the temperate latitudes of the northern hemisphere of cold such as we now experience, for we do not find in strata of that age 15,000 feet thick in Nova Scotia any proofs of intercalated glacial epochs. The peculiar vegetation of the coal was persistent throughout the greater part of the ages required for the deposition of so great a thickness of sediment, in which one forest after another was buried on the spot where it had grown.*

This absence of recurrent periods of cold is perfectly explicable, if I am right in concluding that they can only be brought about by an abnormal quantity of land in high latitudes; for under ordinary geographical conditions a maximum excentricity would only tend to render the climate less equable, and not colder. If the ocean prevailed in the polar regions there would be no permanent snow, or no more than the summer's thaw would dissipate; and the difference in the total quantity of heat being as 1003 to 1000, may, as Sir J. Herschel observed, be neglected, and would, if appreciable, have a heating and not a refrigerating influence.

We may indeed imagine an extreme excentricity and winter in aphelion to have sometimes co-operated, with favourable geographical conditions, to produce an excess of cold, but we know so little of the probable distribution of land in earlier times that I shall not repeat my former attempt to calculate the possible comparative duration of the Glacial and antecedent Tertiary, Secondary, and Primary Epochs by a comparison of the supposed relative amount of change in the organic world which has been brought about in corresponding periods.

Variation in the obliquity of the ecliptic.—Hitherto we have been considering the effect on climate of changes in the excentricity of the orbit, as if the earth's axis of rotation were always inclined, as now, at an angle of 23° 28′ to the plane

* See Elements of Geology by the Author, p. 482.

of the ecliptic; but it is well known that this angle is made to vary by about forty-eight seconds per century by the action of the planets on the earth, by which the plane of the ecliptic is now becoming more nearly coincident from year to year with the equator. This diminution of the obliquity will go on for ages, after which 'it will again increase, and thus oscillate backwards and forwards about a mean position, the extent of its deviation to one side and the other being less than 1° 21'.'* But Sir John Herschel informed me that although this limit as calculated by Laplace is true as regards the last 100,000 years, yet if millions of years are taken into account, it is conceivable that the deviation may possibly be sometimes greater, and may even be found to extend as much as three or even four degrees on each side of the mean.† The questions entered into by Laplace and Leverrier respecting secular changes of the ecliptic relative to a fixed plane, and possible changes in the position of the earth's equator, must be the subject of laborious computations before astronomers will have decided what may be the extreme range of obliquity, but they are agreed that it must be confined within very narrow limits. The result of this movement, whether we adopt the higher or lower limit above alluded to, would be to lessen or augment, according to its direction, the effects to which the precessional movement gives rise. Whenever the obliquity is greater than now, more of the arctic and antarctic regions would be exposed to a long night in winter, and consequently the cold at that season would be greater, and under the opposite circumstances the reverse would take place. The bearing of this cause on geological phenomena would be twofold. So often as the extreme of possible obliquity happened to combine with the maximum excentricity and with geographical circumstances of an abnormal character like those now prevailing in high latitudes, a greater intensity of cold would be produced than could exist without such a combination, and so far this would favour a glacial epoch. But when, on the other hand, the obliquity was at its minimum, the cold would

* Herschel's Astronomy, art. 640.

† Letter to the Author, Oct. 1866.

be lessened, even though all the other conditions which promote it were in full force. It may also be remarked that if the obliquity of the ecliptic could ever be diminished to the extent of four degrees below its present inclination, such a deviation would be of geological interest, in so far as it would cause the sun's light to be disseminated over a broader zone inside of the arctic and antarctic circles. Indeed, if the date of its occurrence in past times could be ascertained, this greater spread of the solar rays, implying a shortening of the polar night, might help in some slight degree to account for a vegetation such as now characterises lower latitudes, having had in the Miocene and Carboniferous periods a much wider range towards the pole. Were an adequate supply of light thus afforded, the warmth required by such a flora would rarely have been wanting in past times, for, according to principles before laid down, a more genial climate would usually prevail in high latitudes, that is to say whenever the earth's geography was in a normal state.

In Mr. Meech's valuable paper, before cited (p. 279), he treats of the effects of altered obliquity; but he states * that his results as to the intensity of solar radiation apply only to the outside of the earth's atmosphere. If his readers fail to bear this in mind, they will be in danger of greatly over-rating the increased heat in polar regions caused by different phases of precession, excentricity, and obliquity of the ecliptic; for a large deduction will probably have to be made for the greater amount of atmosphere through which the calorific rays must pass in very high latitudes.

The investigation of the true calorific effect of the sun's rays for every 5° of altitude, allowing for the increased length of path traversed by the oblique rays, is given by Sir J. Leslie and Mr. Traill.† From this it appears that the total annual quantity of heat received at the equator, latitude 45°, and the poles will be as the numbers 115, 51, and 14 respectively. Even these figures represent the comparative quantity of heat at the higher latitudes as being more than the truth; for they are computed on the supposition of constant

* Meech, Smithsonian Contributions, 1857, pp. 21 and 43.

† Article 'Climate,' Encycl. Britann.

sunshine. As cloud prevails to a greater extent in the high latitudes than at the equator, the disproportion will be increased.

Supposed variations in the temperature of space.—Another astronomical hypothesis respecting the possible cause of secular variations in climate has been proposed by a distinguished mathematician and philosopher, M. Poisson. He begins by assuming, 1st, that the sun and our planetary system are not stationary, but carried onward by a common movement through space. 2dly, that every point in space receives heat as well as light from innumerable stars surrounding it on all sides, so that if a right line of indefinite length be produced in any direction from such point, it must encounter a star either visible or invisible to us. 3dly he then goes on to assume, that the different regions of space, which in the course of millions of years are traversed by our system, must be of very unequal temperature, inasmuch as some of them must receive a greater, others a less quantity of radiant heat from the great stellar enclosure. If the earth, he continues, or any other large body, pass from a hotter to a colder region, it would not readily lose in the second all the heat which it has imbibed in the first region, but retain a temperature increasing downwards from the surface, as is the actual condition of our planet.*

Now the opinion originally suggested by Sir W. Herschel, that our sun and its attendant planets were all moving onward through space, in the direction of the constellation Hercules, is very generally thought by modern astronomers to be confirmed. But the amount of the movement is still uncertain, and great indeed must be its extent before this cause alone can work any material alteration in the terrestrial climates. Mr. Hopkins, when treating of this theory, remarked that so far as we are acquainted with the position of stars not very remote from the sun, they seem to be so distant from each other, that there are no points in space among them where the intensity of radiating heat would be comparable to that which the earth

* Poisson, Théorie mathémat. de la Chaleur, Comptes rendus de l'Acad. des Sci., Jan. 30, 1837.

derives from the sun, except at points very near to each star. Thus, in order that the earth should derive a degree of heat from stellar radiation comparable to that now derived from the sun, it must be in close proximity to some particular star, leaving the aggregate effect of radiation from the other stars nearly the same as at present. This approximation, however, to a single star could not take place consistently with the preservation of the motion of the earth about the sun, according to its present laws.

Suppose our sun should approach a star within the present distance of Neptune. That planet could no longer remain a member of the solar system, and the motions of the other planets would be disturbed in a degree which no one has ever contemplated as probable since the existence of the solar system. But such a star, supposing it to be no larger than the sun, and to emit the same quantity of heat, would not send to the earth much more than one-thousandth part of the heat which she derives from the sun, and would therefore produce only a very small change in terrestrial temperature.*

Supposed gradual diminution of the earth's primitive heat.—The gradual diminution of the supposed primitive heat of the globe has been resorted to by many geologists as the principal cause of alterations of climate. The matter of our planet is imagined, in accordance with the conjectures of Leibnitz, to have been originally in an intensely heated state, and to have been parting ever since with portions of its heat, and at the same time contracting its dimensions. There are, undoubtedly, good grounds for inferring, from recent observation and experiment, that the temperature of the earth increases as we descend from the surface to that slight depth to which man can penetrate; but there are no positive proofs of a secular decrease of internal heat accompanied by contraction. On the contrary, Laplace has shown, by reference to astronomical observations made in the time of Hipparchus, that in the last two thousand years at least there has been no sensible contraction of the globe by cooling;

* Quart. Journ. Geol. Soc. 1852, p. 62.

for had this been the case, even to an extremely small amount, the day would have been shortened, whereas its length has certainly not diminished during that period by $\frac{1}{300}$th of a second.

I shall allude in the second volume to many objections which may be urged against the theory of the intense heat of the earth's central nucleus, and shall then enquire how far the observed augmentation of temperature, as we descend below the surface, may be referable to other causes unconnected with the supposed pristine fluidity of the entire globe.

CHAPTER XIV.

UNIFORMITY IN THE SERIES OF PAST CHANGES IN THE ANIMATE AND INANIMATE WORLD.

SUPPOSED ALTERNATE PERIODS OF REPOSE AND DISORDER—OBSERVED FACTS IN WHICH THIS DOCTRINE HAS ORIGINATED—THESE MAY BE EXPLAINED BY SUPPOSING A UNIFORM AND UNINTERRUPTED SERIES OF CHANGES—THREEFOLD CONSIDERATION OF THIS SUBJECT: FIRST, IN REFERENCE TO THE LAWS WHICH GOVERN THE FORMATION OF FOSSILIFEROUS STRATA, AND THE SHIFTING OF THE AREAS OF SEDIMENTARY DEPOSITION; SECONDLY, IN REFERENCE TO THE LIVING CREATION, EXTINCTION OF SPECIES, AND ORIGIN OF NEW ANIMALS AND PLANTS; THIRDLY, IN REFERENCE TO THE CHANGES PRODUCED IN THE EARTH'S CRUST BY THE CONTINUANCE OF SUBTERRANEAN MOVEMENTS IN CERTAIN AREAS, AND THEIR TRANSFERENCE AFTER LONG PERIODS TO NEW AREAS—ON THE COMBINED INFLUENCE OF ALL THESE MODES AND CAUSES OF CHANGE IN PRODUCING BREAKS AND CHASMS IN THE CHAIN OF RECORDS—CONCLUDING REMARKS ON THE IDENTITY OF THE ANCIENT AND PRESENT SYSTEM OF TERRESTRIAL CHANGES.

Origin of the doctrine of alternate periods of repose and disorder.—IT has been truly observed, that when we arrange the fossiliferous formations in chronological order, they constitute a broken and defective series of monuments: we pass without any intermediate gradations from systems of strata which are horizontal, to other systems which are highly inclined—from rocks of peculiar mineral composition to others which have a character wholly distinct—from one assemblage of organic remains to another, in which frequently nearly all the species, and a large part of the genera, are different. These violations of continuity are so common as to constitute in most regions the rule rather than the exception, and they have been considered by many geologists as conclusive in favour of sudden revolutions in the inanimate and animate world. We have already seen that according to the speculations of some writers, there have been in the past history of the planet alternate periods of

tranquillity and convulsion, the former enduring for ages, and resembling the state of things now experienced by man; the other brief, transient, and paroxysmal, giving rise to new mountains, seas, and valleys, annihilating one set of organic beings, and ushering in the creation of another.

It will be the object of the present chapter to demonstrate that these theoretical views are not borne out by a fair interpretation of geological monuments. It is true that in the solid framework of the globe we have a chronological chain of natural records, many links of which are wanting: but a careful consideration of all the phenomena leads to the opinion that the series was originally defective—that it has been rendered still more so by time—that a great part of what remains is inaccessible to man, and even of that fraction which is accessible nine-tenths or more are to this day unexplored.

The readiest way, perhaps, of persuading the reader that we may dispense with great and sudden revolutions in the geological order of events is by showing him how a regular and uninterrupted series of changes in the animate and inanimate world must give rise to such breaks in the sequence, and such unconformability of stratified rocks, as are usually thought to imply convulsions and catastrophes. It is scarcely necessary to state that the order of events thus assumed to occur, for the sake of illustration, should be in harmony with all the conclusions legitimately drawn by geologists from the structure of the earth, and must be equally in accordance with the changes observed by man to be now going on in the living as well as in the inorganic creation. It may be necessary in the present state of science to supply some part of the assumed course of nature hypothetically; but if so, this must be done without any violation of probability, and always consistently with the analogy of what is known both of the past and present economy of our system. Although the discussion of so comprehensive a subject must carry the beginner far beyond his depth, it will also, it is hoped, stimulate his curiosity, and prepare him to read some elementary treatises on geology with advantage, and teach him the bearing on that science

of the changes now in progress on the earth. At the same time it may enable him the better to understand the intimate connection between the Second and Third Books of this work, one of which is occupied with the changes of the inorganic, the latter with those of the organic creation.

In pursuance, then, of the plan above proposed, I will consider in this chapter, first, the laws which regulate the denudation of strata and the deposition of sediment; secondly, those which govern the fluctuation in the animate world; and thirdly, the mode in which subterranean movements affect the earth's crust.

Uniformity of change considered, first, in reference to denudation and sedimentary deposition.—First, in regard to the laws governing the deposition of new strata. If we survey the surface of the globe, we immediately perceive that it is divisible into areas of deposition and non-deposition; or, in other words, at any given time there are spaces which are the recipients, others which are not the recipients, of sedimentary matter. No new strata, for example, are thrown down on dry land, which remains the same from year to year; whereas, in many parts of the bottom of seas and lakes, mud, sand, and pebbles are annually spread out by rivers and currents. There are also great masses of limestone growing in some seas, chiefly composed of corals and shells, or, as in the depths of the Atlantic, of chalky mud made up of foraminifera and diatomaceæ.

As to the dry land, so far from being the receptacle of fresh accessions of matter, it is exposed almost everywhere to waste away. Forests may be as dense and lofty as those of Brazil, and may swarm with quadrupeds, birds, and insects, yet at the end of thousands of years one layer of black mould a few inches thick may be the sole representative of those myriads of trees, leaves, flowers, and fruits, those innumerable bones and skeletons of birds, quadrupeds, and reptiles, which tenanted the fertile region. Should this land be at length submerged, the waves of the sea may wash away in a few hours the scanty covering of mould, and it may merely impart a darker shade of colour to the next stratum of marl,

sand, or other matter newly thrown down. So also at the bottom of the ocean where no sediment is accumulating, seaweed, zoophytes, fish, and even shells, may multiply for ages and decompose, leaving no vestige of their form or substance behind. Their decay, in water, although more slow, is as certain and eventually as complete as in the open air. Nor can they be perpetuated for indefinite periods in a fossil state, unless imbedded in some matrix which is impervious to water, or which at least does not allow a free percolation of that fluid, impregnated, as it usually is, with a slight quantity of carbonic or other acid. Such a free percolation may be prevented either by the mineral nature of the matrix itself, or by the superposition of an impermeable stratum; but if unimpeded, the fossil shell or bone will be dissolved and removed, particle after particle, and thus entirely effaced, unless petrifaction or the substitution of some mineral for the organic matter happen to take place.

That there has been land as well as sea at all former geological periods, we know from the fact that fossil trees and terrestrial plants are imbedded in rocks of every age, except those which are so ancient as to be very imperfectly known to us. Occasionally lacustrine and fluviatile shells, or the bones of amphibious or land reptiles, point to the same conclusion. The existence of dry land at all periods of the past implies, as before mentioned, the partial deposition of sediment, or its limitation to certain areas; and the next point to which I shall call the reader's attention is the shifting of these areas from one region to another.

First, then, variations in the site of sedimentary deposition are brought about independently of subterranean movements. There is always a slight change from year to year, or from century to century. The sediment of the Rhone, for example, thrown into the Lake of Geneva, is now conveyed to a spot a mile and a half distant from that where it accumulated in the tenth century, and six miles from the point where the delta began originally to form. We may look forward to the period when this lake will be filled up, and then the distribution of the transported matter will be suddenly altered, for the mud and sand brought down from the Alps will thenceforth, instead

of being deposited near Geneva, be carried nearly 200 miles southwards, where the Rhone enters the Mediterranean.

In the deltas of large rivers, such as those of the Ganges and Indus, the mud is first carried down for many centuries through one arm, and on this being stopped up it is discharged by another, and may then enter the sea at a point 50 or 100 miles distant from its first receptacle. The direction of marine currents is also liable to be changed by various accidents, as by the heaping up of new sandbanks, or the wearing away of cliffs and promontories.

But, secondly, all these causes of fluctuation in the sedimentary areas are entirely subordinate to those great upward or downward movements of land, which will presently be spoken of, as prevailing over large tracts of the globe. By such elevation or subsidence certain spaces are gradually submerged, or made gradually to emerge: in the one case sedimentary deposition may be suddenly renewed after having been suspended for one or more geological periods, in the other as suddenly made to cease after having continued for ages.

If deposition be renewed after a long interval, the new strata will usually differ greatly from the sedimentary rocks previously formed in the same place, and especially if the older rocks have suffered derangement, which implies a change in the physical geography of the district since the previous conveyance of sediment to the same spot. It may happen, however, that, even where the two groups, the superior and the inferior, are horizontal and conformable to each other, they may still differ entirely in mineral character, because, since the origin of the older formation, the geography of some distant country has been altered. In that country rocks before concealed may have become exposed by denudation; volcanos may have burst out and covered the surface with scoriæ and lava; or new lakes, intercepting the sediment previously conveyed from the upper country, may have been formed by subsidence; and other fluctuations may have occurred, by which the materials brought down from thence by rivers to the sea have acquired a distinct mineral character.

It is well known that the stream of the Mississippi is charged with sediment of a different colour from that of the Arkansas and Red Rivers, which are tinged with red mud, derived from rocks of porphyry and red gypseous clays in 'the far west.' The waters of the Uruguay, says Darwin, draining a granitic country, are clear and black, those of the Parana, red.* The mud with which the Indus is loaded, says Burnes, is of a clayey hue, that of the Chenab, on the other hand, is reddish, that of the Sutlej is more pale.† The same causes which make these several rivers, sometimes situated at no great distance the one from the other, to differ greatly in the character of their sediment, will make the waters draining the same country at different epochs, especially before and after great revolutions in physical geography, to be entirely dissimilar. It is scarcely necessary to add that marine currents will be affected in an analogous manner in consequence of the formation of new shoals, the emergence of new islands, the subsidence of others, the gradual waste of neighbouring coasts, the growth of new deltas, the increase of coral reefs, volcanic eruptions, and other changes.

Uniformity of change considered, secondly, in reference to the living creation.—Secondly, in regard to the vicissitudes of the living creation, all are agreed that the successive groups of sedimentary strata found in the earth's crust are not only dissimilar in mineral composition for reasons above alluded to, but are likewise distinguishable from each other by their organic remains. The general inference drawn from the study and comparison of the various groups, arranged in chronological order, is this: that at successive periods distinct tribes of animals and plants have inhabited the land and waters, and that the organic types of the newer formations are more analogous to species now existing than those of more ancient rocks. If we then turn to the present state of the animate creation, and enquire whether it has now become fixed and stationary, we discover that, on the contrary, it is in a state of continual flux—that there are many causes

* Darwin's Journal, p. 163, 2nd ed. p. 139.

† Journ. Roy. Geograph. Soc., vol. iii. p. 142.

in action which tend to the extinction of species, and which are conclusive against the doctrine of their unlimited durability.

There are also causes which give rise to new varieties and races in plants and animals, and new forms are continually supplanting others which had endured for ages. But natural history has been successfully cultivated for so short a period, that a few examples only of local, and perhaps but one or two of absolute, extirpation of species can as yet be proved, and these only where the interference of man has been conspicuous. It will nevertheless appear evident, from the facts and arguments detailed in the chapters which treat of the geographical distribution of species in the next volume, that man is not the only exterminating agent; and that, independently of his intervention, the annihilation of species is promoted by the multiplication and gradual diffusion of every animal or plant. It will also appear that every alteration in the physical geography and climate of the globe cannot fail to have the same tendency. If we proceed still farther, and enquire whether new species are substituted from time to time for those which die out, we find that the successive introduction of new forms appears to have been a constant part of the economy of the terrestrial system, and if we have no direct proof of the fact it is because the changes take place so slowly as not to come within the period of exact scientific observation. To enable the reader to appreciate the gradual manner in which a passage may have taken place from an extinct fauna to that now living, I shall say a few words on the fossils of successive Tertiary periods. When we trace the series of formations from the more ancient to the more modern, it is in these Tertiary deposits that we first meet with assemblages of organic remains having a near analogy to the fauna of certain parts of the globe in our own time. In the Eocene, or oldest subdivisions, some few of the testacea belong to existing species, although almost all of them, and apparently all the associated vertebrata, are now extinct. These Eocene strata are succeeded by a great number of more modern deposits, which depart gradually in the

character of their fossils from the Eocene type, and approach more and more to that of the living creation. In the present state of science, it is chiefly by the aid of shells that we are enabled to arrive at these results, for of all classes the testacea are the most generally diffused in a fossil state, and may be called the medals principally employed by nature in recording the chronology of past events. In the Upper Miocene rocks (No. 5 of the table, p. 135) we begin to find a considerable number, although still a minority, of recent species, intermixed with some fossils common to the preceding, or Eocene, epoch. We then arrive at the Pliocene strata, in which species now contemporary with man begin to preponderate, and in the newest of which nine-tenths of the fossils agree with species still inhabiting the neighbouring sea. It is in the Post-Tertiary strata, where all the shells agree with species now living, that we have discovered the first or earliest known remains of man associated with the bones of quadrupeds, some of which are of extinct species.

In thus passing from the older to the newer members of the Tertiary system, we meet with many chasms, but none which separate entirely, by a broad line of demarcation, one state of the organic world from another. There are no signs of an abrupt termination of one fauna and flora, and the starting into life of new and wholly distinct forms. Although we are far from being able to demonstrate geologically an insensible transition from the Eocene to the Miocene, or even from the latter to the recent fauna, yet the more we enlarge and perfect our general survey, the more nearly do we approximate to such a continuous series, and the more gradually are we conducted from times when many of the genera and nearly all the species were extinct, to those in which scarcely a single species flourished which we do not know to exist at present. Dr. A. Philippi, indeed, after an elaborate comparison of the fossil tertiary shells of Sicily with those now living in the Mediterranean, announced, as the result of his examination, that there are strata in that island which attest a very gradual passage from a period when only thirteen in a hundred of the shells were like the species now

living in the sea, to an era when the recent species had attained a proportion of ninety-five in a hundred. There is, therefore, evidence, he says, in Sicily of this revolution in the animate world having been effected 'without the intervention of any convulsion or abrupt changes, certain species having from time to time died out, and others having been introduced, until at length the existing fauna was elaborated.'

In no part of Europe is the absence of all signs of man or his works, in strata of comparatively modern date, more striking than in Sicily. In the central parts of that island we observe a lofty table-land and hills, sometimes rising to the height of 3,000 feet, capped with a limestone, in which from 70 to 85 per cent. of the fossil testacea are specifically identical with those now inhabiting the Mediterranean. These calcareous and other argillaceous strata of the same age are intersected by deep valleys which appear to have been gradually formed by denudation, but have not varied materially in width or depth since Sicily was first colonised by the Greeks. The limestone, moreover, which is of so late a date in geological chronology, was quarried for building those ancient temples of Girgenti and Syracuse, of which the ruins carry us back to a remote era in human history. If we are lost in conjectures when speculating on the ages required to lift up these formations to the height of several thousand feet above the sea, and to excavate the valleys, how much more remote must be the era when the same rocks were gradually formed beneath the waters!

The intense cold of the Glacial period was spoken of in the tenth chapter. Although we have not yet succeeded in detecting proofs of the origin of man antecedently to that epoch, we have yet found evidence that most of the testacea, and not a few of the quadrupeds, which preceded, were of the same species as those which followed the extreme cold. To whatever local disturbances this cold may have given rise in the distribution of species, it seems to have done little in effecting their annihilation. We may conclude therefore, from a survey of the tertiary and modern strata, which constitute a more complete and unbroken series than rocks of older date, that the extinction and creation of species

have been, and are, the result of a slow and gradual change in the organic world.

Uniformity of change considered, thirdly, in reference to subterranean movements.—Thirdly, to pass on to the last of the three topics before proposed for discussion, the reader will find, in the account given in the Second Book, Vol. II., of the earthquakes recorded in history, that certain countries have, from time immemorial, been rudely shaken again and again; while others, comprising by far the largest part of the globe, have remained to all appearance motionless. In the regions of convulsion rocks have been rent asunder, the surface has been forced up into ridges, chasms have opened, or the ground throughout large spaces has been permanently lifted up above or let down below its former level. In the regions of tranquillity some areas have remained at rest, but others have been ascertained, by a comparison of measurements made at different periods, to have risen by an insensible motion, as in Sweden, or to have subsided very slowly, as in Greenland. That these same movements, whether ascending or descending, have continued for ages in the same direction has been established by historical or geological evidence. Thus we find on the opposite coasts of Sweden that brackish water deposits, like those now forming in the Baltic, occur on the eastern side, and upraised strata filled with purely marine shells, now proper to the ocean, on the western coast. Both of these have been lifted up to an elevation of several hundred feet above high-water mark. The rise within the historical period has not amounted to many yards, but the greater extent of antecedent upheaval is proved by the occurrence in inland spots, several hundred feet high, of deposits filled with fossil shells of species now living either in the ocean or the Baltic.*

It must in general be more difficult to detect proofs of slow and gradual subsidence than of elevation, but the theory which accounts for the form of circular coral reefs and lagoon islands, and which will be explained in the concluding chapter of this work, will satisfy the reader that there are spaces on the globe, several thousand miles in circumference,

* See vol. ii. p. 185.

throughout which the downward movement has predominated for ages, and yet the land has never, in a single instance, gone down suddenly for several hundred feet at once. Yet geology demonstrates that the persistency of subterranean movements in one direction has not been perpetual throughout all past time. There have been great oscillations of level, by which a surface of dry land has been submerged to a depth of several thousand feet, and then at a period long subsequent raised again and made to emerge. Nor have the regions now motionless been always at rest; and some of those which are at present the theatres of reiterated earthquakes have formerly enjoyed a long continuance of tranquillity. But, although disturbances have ceased after having long prevailed, or have recommenced after a suspension for ages, there has been no universal disruption of the earth's crust or desolation of the surface since times the most remote. The non-occurrence of such a general convulsion is proved by the perfect horizontality now retained by some of the most ancient fossiliferous strata throughout wide areas.

That the subterranean forces have visited different parts of the globe at successive periods is inferred chiefly from the unconformability of strata belonging to groups of different ages. Thus, for example, on the borders of Wales and Shropshire, we find the slaty beds of the ancient Silurian system inclined and vertical, while the beds of the overlying carboniferous shale and sandstone are horizontal. All are agreed that in such a case the older set of strata had suffered great disturbance before the deposition of the newer or carboniferous beds, and that these last have never since been violently fractured, nor have ever been bent into folds, whether by sudden or continuous lateral pressure. On the other hand, the more ancient or Silurian group suffered only a local derangement, and neither in Wales nor elsewhere are all the rocks of that age found to be curved or vertical.

In various parts of Europe, for example, and particularly near Lake Wener in the south of Sweden, and in many parts of Russia, the Silurian strata maintain the most perfect horizontality; and a similar observation may be made respecting

limestones and shales of like antiquity in the great lake district of Canada and the United States. These older rocks are still as flat and horizontal as when first formed; yet, since their origin, not only have most of the actual mountain-chains been uplifted, but some of the very rocks of which those mountains are composed have been formed, some of them by igneous and others by aqueous action.

It would be easy to multiply instances of similar unconformability in formations of other ages; but a few more will suffice. The carboniferous rocks before alluded to as horizontal on the borders of Wales are vertical in the Mendip hills in Somersetshire, where the overlying beds of the New Red Sandstone are horizontal. Again, in the Wolds of Yorkshire the last-mentioned sandstone supports on its curved and inclined beds the horizontal Chalk. The Chalk again is vertical on the flanks of the Pyrenees, and the tertiary strata repose unconformably upon it.

As almost every country supplies illustrations of the same phenomena, they who advocate the doctrine of alternate periods of disorder and repose may appeal to the facts above described, as proving that every district has been by turns convulsed by earthquakes and then respited for ages from convulsions. But so it might with equal truth be affirmed that every part of Europe has been visited alternately by winter and summer, although it has always been winter and always summer in some part of the planet, and neither of these seasons has ever reigned simultaneously over the entire globe. They have been always shifting from place to place; but the vicissitudes which recur thus annually in a single spot are never allowed to interfere with the invariable uniformity of seasons throughout the whole planet.

So, in regard to subterranean movements, the theory of the perpetual uniformity of the force which they exert on the earth's crust is quite consistent with the admission of their alternate development and suspension for long and indefinite periods within limited geographical areas.

If, for reasons before stated, we assume a continual extinction of species and appearance of others on the globe, it will then follow that the fossils of strata formed at two distant

periods on the same spot will differ even more certainly than the mineral composition of those strata. For rocks of the same kind have sometimes been reproduced in the same district after a long interval of time; whereas all the evidence derived from fossil remains is in favour of the opinion that species which have once died out have never been reproduced. The submergence, then, of land must be often attended by the commencement of a new class of sedimentary deposits, characterised by a new set of fossil animals and plants, while the reconversion of the bed of the sea into land may arrest at once and for an indefinite time the formation of geological monuments. Should the land again sink, strata will again be formed; but one or many entire revolutions in animal or vegetable life may have been completed in the interval.

As to the want of completeness in the fossiliferous series, which may be said to be almost universal, we have only to reflect on what has been already said of the laws governing sedimentary deposition, and those which give rise to fluctuations in the animate world, to be convinced that a very rare combination of circumstances can alone give rise to such a superposition and preservation of strata as will bear testimony to the gradual passage from one state of organic life to another. To produce such strata nothing less will be requisite than the fortunate coincidence of the following conditions: first, a never-failing supply of sediment in the same region throughout a period of vast duration; secondly, the fitness of the deposit in every part for the permanent preservation of imbedded fossils; and, thirdly, a gradual subsidence to prevent the sea or lake from being filled up and converted into land.

It will appear in the chapter on coral reefs,* that, in certain parts of the Pacific and Indian Oceans, most of these conditions, if not all, are complied with, and the constant growth of coral, keeping pace with the sinking of the bottom of the sea, seems to have gone on so slowly, for such indefinite periods, that the signs of a gradual change in organic

* See last chapter of Vol. II. of this work.

life might probably be detected in that quarter of the globe if we could explore its submarine geology. Instead of the growth of coralline limestone, let us suppose, in some other place, the continuous deposition of fluviatile mud and sand, such as the Ganges and Brahmapootra have poured for thousands of years into the Bay of Bengal. Part of this bay, although of considerable depth, might at length be filled up before an appreciable amount of change was effected in the fish, mollusca, and other inhabitants of the sea and neighbouring land. But if the bottom be lowered by sinking at the same rate that it is raised by fluviatile mud, the bay can never be turned into dry land. In that case one new layer of matter may be superimposed upon another for a thickness of many thousand feet, and the fossils of the inferior beds may differ greatly from those entombed in the uppermost, yet every intermediate gradation may be indicated in the passage from an older to a newer assemblage of species. Granting, however, that such an unbroken sequence of monuments may thus be elaborated in certain parts of the sea, and that the strata happen to be all of them well adapted to preserve the included fossils from decomposition, how many accidents must still concur before these submarine formations will be laid open to our investigation! The whole deposit must first be raised several thousand feet, in order to bring into view the very foundation; and during the process of exposure the superior beds must not be entirely swept away by denudation.

In the first place, the chances are nearly as three to one against the mere emergence of the mass above the waters, because nearly three-fourths of the globe are covered by the ocean. But if it be upheaved and made to constitute part of the dry land, it must also, before it can be available for our instruction, become part of that area already surveyed by geologists. In this small fraction of land already explored, and still very imperfectly known, we are required to find a set of strata deposited under peculiar conditions, and which, having been originally of limited extent, would have been probably much lessened by subsequent denudation.

Yet it is precisely because we do not encounter at every

step the evidence of such gradations from one state of the organic world to another, that so many geologists have embraced the doctrine of great and sudden revolutions in the history of the animate world. Not content with simply availing themselves, for the convenience of classification, of those gaps and chasms which here and there interrupt the continuity of the chronological series, as at present known, they deduce, from the frequency of these breaks in the chain of records, an irregular mode of succession in the events themselves, both in the organic and inorganic world. But, besides that some links of the chain which once existed are now entirely lost and others concealed from view, we have good reason to suspect that it was never complete originally. It may undoubtedly be said that strata have been always forming somewhere, and therefore at every moment of past time Nature has added a page to her archives; but, in reference to this subject, it should be remembered that we can never hope to compile a consecutive history by gathering together monuments which were originally detached and scattered over the globe. For, as the species of organic beings contemporaneously inhabiting remote regions are distinct, the fossils of the first of several periods which may be preserved in any one country, as in America for example, will have no connection with those of a second period found in India, and will therefore no more enable us to trace the signs of a gradual change in the living creation, than a fragment of Chinese history will fill up a blank in the political annals of Europe.

The absence of any deposits of importance containing recent shells in Chili, or anywhere on the western coast of South America, naturally led Mr. Darwin to the conclusion that 'where the bed of the sea is either stationary or rising, circumstances are far less favourable than where the level is sinking to the accumulation of conchiferous strata of sufficient thickness and extension to resist the average vast amount of denudation.' * In like manner the beds of superficial sand, clay, and gravel, with recent shells, on the coasts of Norway

* Darwin's S. America, pp. 136, 139.

and Sweden, where the land has risen in Post-tertiary times, are so thin and scanty as to incline us to admit a similar proposition. We may in fact assume that in all cases where the bottom of the sea has been undergoing continuous elevation, the total thickness of sedimentary matter accumulating at depths suited to the habitation of most of the species of shells can never be great, nor can the deposits be thickly covered by superincumbent matter, so as to be consolidated by pressure. When they are upheaved, therefore, the waves on the beach will bear down and disperse the loose materials; whereas, if the bed of the sea subsides slowly, a mass of strata, containing abundance of such species as live at moderate depths, may be formed and may increase in thickness to any amount. It may also extend horizontally over a broad area, as the water gradually encroaches on the subsiding land.

Hence it will follow that great violations of continuity in the chronological series of fossiliferous rocks will always exist, and the imperfection of the record, though lessened, will never be removed by future discoveries. For not only will no deposits originate on the dry land, but those formed in the sea near land, which is undergoing constant upheaval, will usually be too slight in thickness to endure for ages.

In proportion as we become acquainted with larger geographical areas, many of the gaps, by which a chronological table, like that given at page 135, is rendered defective, will be removed. We were enabled by aid of the labours of Prof. Sedgwick and Sir Roderick Murchison, to intercalate, in 1838, the marine strata of the Devonian period, with their fossil shells, corals, and fish, between the Silurian and Carboniferous rocks. Previously the marine fauna of these last-mentioned formations wanted the connecting links which now render the passage from the one to the other much less abrupt. In like manner the Upper Miocene has no representative in England, but in France, Germany, and Switzerland it constitutes a most instructive link between the living creation and the middle of the great Tertiary period. Still we must expect, for reasons before stated, that

chasms will for ever continue to occur, in some parts of our sedimentary series.

Concluding remarks on the consistency of the theory of gradual change with the existence of great breaks in the series.— To return to the general argument pursued in this chapter, it is assumed, for reasons above explained, that a slow change of species is in simultaneous operation everywhere throughout the habitable surface of sea and land; whereas the fossilisation of plants and animals is confined to those areas where new strata are produced. These areas, as we have seen, are always shifting their position, so that the fossilising process, by means of which the commemoration of the particular state of the organic world, at any given time, is effected, may be said to move about, visiting and revisiting different tracts in succession.

To make still more clear the supposed working of this machinery, I shall compare it to a somewhat analogous case that might be imagined to occur in the history of human affairs. Let the mortality of the population of a large country represent the successive extinction of species, and the births of new individuals the introduction of new species. While these fluctuations are gradually taking place everywhere, suppose commissioners to be appointed to visit each province of the country in succession, taking an exact account of the number, names, and individual peculiarities of all the inhabitants, and leaving in each district a register containing a record of this information. If, after the completion of one census, another is immediately made on the same plan, and then another, there will at last be a series of statistical documents in each province. When those belonging to any one province are arranged in chronological order, the contents of such as stand next to each other will differ according to the length of the intervals of time between the taking of each census. If, for example, there are sixty provinces, and all the registers are made in a single year and renewed annually, the number of births and deaths will be so small, in proportion to the whole of the inhabitants, during the interval between the compiling of two consecutive documents, that the individuals described in such documents will be

nearly identical; whereas, if the survey of each of the sixty provinces occupies all the commissioners for a whole year, so that they are unable to revisit the same place until the expiration of sixty years, there will then be an almost entire discordance between the persons enumerated in two consecutive registers in the same province. There are, undoubtedly, other causes, besides the mere quantity of time, which may augment or diminish the amount of discrepancy. Thus, at some periods a pestilential disease may have lessened the average duration of human life; or a variety of circumstances may have caused the births to be unusually numerous, and the population to multiply; or a province may be suddenly colonised by persons migrating from surrounding districts.

These exceptions may be compared to the accelerated rate of fluctuations in the fauna and flora of a particular region, in which the climate and physical geography may be undergoing an extraordinary degree of alteration.

But I must remind the reader that the case above proposed has no pretensions to be regarded as an exact parallel to the geological phenomena which I desire to illustrate; for the commissioners are supposed to visit the different provinces in rotation; whereas the commemorating processes by which organic remains become fossilised, although they are always shifting from one area to the other, are yet very irregular in their movements. They may abandon and revisit many spaces again and again, before they once approach another district; and, besides this source of irregularity, it may often happen that, while the depositing process is suspended, denudation may take place, which may be compared to the occasional destruction by fire or other causes of some of the statistical documents before mentioned. It is evident that where such accidents occur the want of continuity in the series may become indefinitely great, and that the monuments which follow next in succession will by no means be equidistant from each other in point of time.

If this train of reasoning be admitted, the occasional distinctness of the fossil remains, in formations immediately in contact, would be a necessary consequence of the existing

laws of sedimentary deposition and subterranean movement, accompanied by a constant dying-out and renovation of species.

As all the conclusions above insisted on are directly opposed to opinions still popular, I shall add another comparison, in the hope of preventing any possible misapprehension of the argument. Suppose we had discovered two buried cities at the foot of Vesuvius, immediately superimposed upon each other, with a great mass of tuff and lava intervening, just as Portici and Resina, if now covered with ashes, would overlie Herculaneum. An antiquary might possibly be entitled to infer, from the inscriptions on public edifices, that the inhabitants of the inferior and older city were Greeks, and those of the modern towns Italians. But he would reason very hastily if he also concluded from these data, that there had been a sudden change from the Greek to the Italian language in Campania. But if he afterwards found *three* buried cities, one above the other, the intermediate one being Roman, while, as in the former example, the lowest was Greek and the uppermost Italian, he would then perceive the fallacy of his former opinion, and would begin to suspect that the catastrophes, by which the cities were inhumed, might have no relation whatever to the fluctuations in the language of the inhabitants; and that, as the Roman tongue had evidently intervened between the Greek and Italian, so many other dialects may have been spoken in succession, and the passage from the Greek to the Italian may have been very gradual, some terms growing obsolete, while others were introduced from time to time.

If this antiquary could have shown that the volcanic paroxysms of Vesuvius were so governed as that cities should be buried one above the other, just as often as any variation occurred in the language of the inhabitants, then, indeed, the abrupt passage from a Greek to a Roman, and from a Roman to an Italian city, would afford proof of fluctuations no less sudden in the language of the people.

So, in Geology, if we could assume that it is part of the plan of Nature to preserve, in every region of the globe, an unbroken series of monuments to commemorate the vicissi-

tudes of the organic creation, we might infer the sudden extirpation of species, and the simultaneous introduction of others, as often as two formations in contact are found to include dissimilar organic fossils. But we must shut our eyes to the whole economy of the existing causes, aqueous, igneous, and organic, if we fail to perceive *that such is not the plan of Nature.*

I shall now conclude the discussion of a question with which we have been occupied since the beginning of the fifth chapter—namely, whether there has been any interruption, from the remotest periods, of one uniform and continuous system of change in the animate and inanimate world. We were induced to enter into that enquiry by reflecting how much the progress of opinion in Geology had been influenced by the assumption that the analogy was slight in kind, and still more slight in degree, between the causes which produced the former revolutions of the globe, and those now in every-day operation. It appeared clear that the earlier geologists had not only a scanty acquaintance with existing changes, but were singularly unconscious of the amount of their ignorance. With the presumption naturally inspired by this unconsciousness, they had no hesitation in deciding at once that time could never enable the existing powers of nature to work out changes of great magnitude, still less such important revolutions as those which are brought to light by Geology. They therefore felt themselves at liberty to indulge their imaginations in guessing at what *might be*, rather than enquiring *what is*; in other words, they employed themselves in conjecturing what might have been the course of Nature at a remote period, rather than in the investigation of what was the course of Nature in their own times.

It appeared to them far more philosophical to speculate on the possibilities of the past, than patiently to explore the realities of the present; and having invented theories under the influence of such maxims, they were consistently unwilling to test their validity by the criterion of their accordance with the ordinary operations of Nature. On the contrary, the claims of each new hypothesis to credibility appeared

enhanced by the great contrast, in kind or intensity, of the causes referred to and those now in operation.

Never was there a dogma more calculated to foster indolence, and to blunt the keen edge of curiosity, than this assumption of the discordance between the ancient and existing causes of change. It produced a state of mind unfavourable in the highest degree to the candid reception of the evidence of those minute but incessant alterations which every part of the earth's surface is undergoing, and by which the condition of its living inhabitants is continually made to vary. The student, instead of being encouraged with the hope of interpreting the enigmas presented to him in the earth's structure—instead of being prompted to undertake laborious enquiries into the natural history of the organic world, and the complicated effects of the igneous and aqueous causes now in operation—was taught to despond from the first. Geology, it was affirmed, could never rise to the rank of an exact science; the greater number of phenomena must for ever remain inexplicable, or only be partially elucidated by ingenious conjectures. Even the mystery which invested the subject was said to constitute one of its principal charms, affording, as it did, full scope to the fancy to indulge in a boundless field of speculation.

The course directly opposed to this method of philosophising consists in an earnest and patient enquiry, how far geological appearances are reconcilable with the effect of changes now in progress, or which may be in progress in regions inaccessible to us, but of which the reality is attested by volcanos and subterranean movements. It also endeavours to estimate the aggregate result of ordinary operations multiplied by time, and cherishes a sanguine hope that the resources to be derived from observation and experiment, or from the study of Nature such as she now is, are very far from being exhausted. For this reason all theories are rejected which involve the assumption of sudden and violent catastrophes and revolutions of the whole earth, and its inhabitants—theories which are restrained by no reference to existing analogies, and in which a desire is manifested to cut, rather than patiently to untie, the Gordian knot.

We have now, at least, the advantage of knowing, from experience, that an opposite method has always put geologists on the road that leads to truth—suggesting views which, although imperfect at first, have been found capable of improvement, until at last adopted by universal consent; while the method of speculating on a former distinct state of things and causes has led invariably to a multitude of contradictory systems, which have been overthrown one after the other—have been found incapable of modification—and which have often required to be precisely reversed.

The remainder of this work will be devoted to an investigation of the changes now going on in the crust of the earth and its inhabitants. The importance which the student will attach to such researches will mainly depend on the degree of confidence which he feels in the principles above expounded. If he firmly believes in the resemblance or identity of the ancient and present system of terrestrial changes, he will regard every fact collected respecting the causes in diurnal action as affording him a key to the interpretation of some mystery in the past. Events which have occurred at the most distant periods in the animate and inanimate world will be acknowledged to throw light on each other, and the deficiency of our information respecting some of the most obscure parts of the present creation will be removed. For as, by studying the external configuration of the existing land and its inhabitants, we may restore in imagination the appearance of the ancient continents which have passed away, so may we obtain from the deposits of ancient seas and lakes an insight into the nature of the subaqueous processes now in operation, and of many forms of organic life which, though now existing, are veiled from sight. Rocks, also, produced by subterranean fire in former ages, at great depths in the bowels of the earth, present us, when upraised by gradual movements, and exposed to the light of heaven, with an image of those changes which the deep-seated volcano may now occasion in the nether regions. Thus, although we are mere sojourners on the surface of the planet, chained to a mere point in space, enduring but for a moment of time, the human mind is not only enabled to number worlds beyond

the unassisted ken of mortal eye, but to trace the events of indefinite ages before the creation of our race, and is not even withheld from penetrating into the dark secrets of the ocean, or the interior of the solid globe; free, like the spirit which the poet described as animating the universe,

> ———ire per omnes
> Terrasque, tractusque maris, cœlumque profundum.

BOOK II.

CHANGES IN THE INORGANIC WORLD NOW IN PROGRESS.

CHAPTER XV.

AQUEOUS CAUSES.

DIVISION OF THE SUBJECT INTO CHANGES OF THE ORGANIC AND INORGANIC WORLD—INORGANIC CAUSES OF CHANGE DIVIDED INTO AQUEOUS AND IGNEOUS—AQUEOUS CAUSES FIRST CONSIDERED—FALL OF RAIN—RECENT RAIN-PRINTS IN MUD—EARTH-PYRAMIDS FORMED BY RAIN IN THE TYROL AND SWISS ALPS—DWARF'S TOWER NEAR VIESCH—DESTROYING AND TRANSPORTING POWER OF RUNNING WATER—NEWLY-FORMED VALLEYS IN GEORGIA—SINUOSITIES OF RIVERS—TWO STREAMS WHEN UNITED DO NOT OCCUPY A BED OF DOUBLE SURFACE—INUNDATIONS IN SCOTLAND—FLOODS CAUSED BY LANDSLIPS IN THE WHITE MOUNTAINS—BURSTING OF A LAKE IN SWITZERLAND—DEVASTATIONS CAUSED BY THE ANIO AT TIVOLI—EXCAVATIONS IN THE LAVAS OF ETNA BY SICILIAN RIVERS—GORGE OF THE SIMETO—GRADUAL RECESSION OF THE CATARACT OF NIAGARA.

GEOLOGY was defined to be the science which investigates the former changes that have taken place in the organic as well as in the inorganic kingdoms of Nature. As vicissitudes in the inorganic world are most apparent, and as on them many fluctuations in the animate creation must depend, they may claim our first consideration. The great agents of change in the inorganic world may be divided into two principal classes, the aqueous and the igneous. To the aqueous belong Rain, Rivers, Springs, Currents, and Tides, and the action of Frost and Snow; to the igneous, Volcanos and Earthquakes. Both these classes are instruments of degradation as well as of reproduction; but they may also be regarded as antagonist forces. For the aqueous agents are incessantly labouring to reduce the inequalities of the earth's surface to a level; while the igneous are equally active in restoring

the unevenness of the external crust, partly by heaping up new matter in certain localities, and partly by depressing one portion, and forcing out another, of the earth's envelope.

It is difficult, in a scientific arrangement, to give an accurate view of the combined effects of so many forces in simultaneous operation; because when we consider them separately, we cannot easily estimate either the extent of their efficacy or the kind of results which they produce. We are in danger, therefore, when we attempt to examine the influence exerted singly by each, of overlooking the modifications which they produce on one another; and these are so complicated, that sometimes the igneous and aqueous forces co-operate to produce a joint effect, to which neither of them unaided by the other could give rise,—as when repeated earthquakes unite with running water to widen a valley; or when a thermal spring rises up from a great depth, and conveys the mineral ingredients with which it is impregnated from the interior of the earth to the surface. Sometimes the organic combine with the inorganic causes; as when a reef, composed of shells and corals, protects one line of coast from the destroying power of tides or currents, and turns them against some other point; or when drift timber, floated into a lake, fills a hollow to which the stream would not have had sufficient velocity to convey earthy sediment.

It is necessary, however, to divide our observations on these various causes, and to classify them systematically, endeavouring as much as possible to keep in view that the effects in nature are mixed and not simple, as they may appear in an artificial arrangement.

In treating, in the first place, of the aqueous causes, we may consider them under two divisions; first, those which are connected with the circulation of water from the land to the sea, under which are included the phenomena of rain, rivers, glaciers, and springs; secondly, those which arise from the movements of water in lakes, seas, and the ocean, wherein are comprised the phenomena of waves, tides, and currents. In turning our attention to the former division, we find that the effects of rivers may be subdivided into, first, those of a destroying and transporting, and, secondly, those

of a renovating nature; in the former are included the erosion of rocks and the transportation of matter to lower levels; in the renovating class, the formation of deltas by the influx of sediment, and the shallowing of seas; but these processes are so intimately related to each other, that it will not always be possible to consider them under their separate heads.

ACTION OF RAIN.

Variations in average rainfall.—It is well known that the capacity of the atmosphere to absorb aqueous vapour, and hold it in suspension, increases with every increment of temperature. This capacity is also found to augment in a higher ratio than the augmentation of the heat. Hence, as was first suggested by the geologist Dr. Hutton, when two volumes of air, of different temperatures, both saturated with moisture, mingle together, clouds and rain are produced, for a mean degree of heat having resulted from the union of the two moist airs, the excess of vapour previously held in suspension by the warmer of the two is given out, and if it be in sufficient abundance is precipitated in the form of rain.

As the temperature of the atmosphere diminishes gradually from the equator towards the pole, the evaporation of water and the quantity of rain diminish also. According to Humboldt's computation, the average annual depth of rain at the equator is 96 inches, while in lat. 45° it is only 29 inches, and in lat. 60° not more than 17 inches. But there are so many disturbing causes, that the actual discharge, in any given locality, may deviate very widely from this rule. In England, for example, where the average fall at London is 24½ inches, as ascertained at the Greenwich Observatory, there is such irregularity in some districts, that while at Whitehaven, in Cumberland, there fell in 1849, 32 inches, the quantity of rain in Borrowdale, near Keswick (only 15 miles to the eastward), was no less than 142 inches! * As a rule, the amount of rain in the mountainous parts of Great Britain is more than double that which falls in the less elevated regions. The mean yearly fall of rain at Upsala,

* Miller, Phil. Trans. 1851, p. 165.

near the shores of the Baltic, lat. 60° N., is nearly 16 inches, while at Bergen on the Atlantic coast, in the same lat. and only 440 miles distant, the fall, according to Professor J. D. Forbes, is 77 inches. This difference arises from the position of Bergen on the shore of the ocean where the prevailing westerly winds discharge their moisture before crossing Norway and Sweden, on their way to the borders of the Baltic. Winds blowing from the sea are generally surcharged with moisture, while those blowing from the land are comparatively dry, and it is almost everywhere found that the quantity of rain diminishes as we proceed from the borders of the ocean into the interior of continents. In India, Colonel Sykes found by observations made in 1847 and 1848 that at places situated between 17° and 18° north lat., on a line drawn across the Western Ghauts in the Deccan, the average fall of rain, diminishing as we proceed eastward, varied from 219 to 21 inches.* The annual average in Bengal is probably below 80 inches, yet Dr. Joseph Hooker witnessed at Chirapoonjee, in the year 1850, a fall of 30 inches in 24 hours, and in the same place during a residence of six months (from June to November) 530 inches! This occurred on the south face of the Khasia (or Garrow) mountains in Eastern Bengal (see map, p. 468), where the fall during the whole of the same year probably exceeded 600 inches. So extraordinary a discharge of water is very local, as will presently be seen, and may be thus accounted for. Warm, southerly winds, blowing over the Bay of Bengal, and becoming laden with vapour during their passage, reach the low level delta of the Ganges and Brahmapootra, where the ordinary heat exceeds that of the sea, and where evaporation is constantly going on from countless marshes and the arms of the great rivers. A mingling of two masses of damp air of different temperatures probably causes the fall of 70 or 80 inches of rain, which takes place on the plains. The monsoon, having crossed the delta, impinges on the Khasia mountains, which rise abruptly from the plain to a mean elevation of between 4,000 and 5,000 feet. Here the wind not only encounters the cold air of the mountains, but, what is far more effective as a refrigerating

* Phil. Trans. 1850, p. 354.

cause, the aërial current is made to flow upwards, and to ascend to a height of several thousand feet above the sea. Both the air and the vapour contained in it, being thus relieved of much atmospheric pressure, expand suddenly and are cooled by rarefaction. The vapour is condensed, and about 500 inches of rain are thrown down annually, nearly twenty times as much as falls in Great Britain in a year, and almost all of it poured down in six months. The channel of every torrent and river is swollen at this season, and much sandstone and other rocks are reduced to sand and gravel by the flooded streams. So great is the superficial waste (or *denudation*), that what would otherwise be a rich and luxuriantly wooded region, is converted into a wild and barren moorland.

After the current of warm air has been thus drained of a large portion of its moisture, it still continues its northerly course to the opposite flank of the Khasia range, only 20 miles farther north, and here the fall of rain is reduced to 70 inches in the year. The same wind then blows northwards across the valley of the Brahmapootra, and at length arrives so dry and exhausted at the Bhootan Himalaya (lat. 28° N.), that those mountains, up to the height of 5,000 feet, are naked and sterile, and all their outer valleys arid and dusty. The aërial current still continuing its northerly course and ascending to a higher region, becomes further cooled, condensation again ensues, and Bhootan, above 5,000 feet, is densely clothed with vegetation.*

In another part of India, immediately to the westward, similar phenomena are repeated. The same warm and humid winds, copiously charged with aqueous vapour from the Bay of Bengal, hold their course due north for 300 miles, across the flat and hot plains of the Ganges, till they encounter the lofty Sikkim mountains. (See map, p. 468.) On the southern flank of these they discharge such a deluge of rain that the rivers in the rainy season rise twelve feet in as many hours. Numerous landslips, some of them extending three or four thousand feet along the face of the mountains, composed of fragments of granite, gneiss, and slate, descend into the beds of streams, and dam them up for a time, causing

* Hooker's Himalayan Journal, ined.

temporary lakes, which soon burst their barriers. 'Day and night,' says Dr. Hooker, 'we heard the crashing of falling trees, and the sound of boulders thrown violently against each other in the beds of torrents. By such wear and tear rocky fragments swept down from the hills are in part converted into sand and fine mud; and the turbid Ganges, during its inundation, derives more of its sediment from this source than from the waste of the fine clay of the alluvial plains below.'*

In the districts above alluded to, and in other regions on the verge of the tropics, a greater quantity of rain falls annually than at the equator.

Rainless regions are generally situated in the interior of great continents, as in the great Sahara of Africa, and in parts of Arabia and Persia. In these cases, the moisture which the winds derive from the nearest sea is expended on the lands nearer the coasts. If there are exceptions to this rule, or coast regions destitute of rain, as that extending from the north of Chili in lat. 30° south to Peru in lat. 8° south, it is where the prevailing winds are intercepted by a chain like the Andes, and made to part with all their moisture before they reach the lower regions to the leeward.

From such facts the reader will infer that in the course of successive geological periods there will be great variations in the quantity of rain falling in one and the same region. At one period there may be no rain during the year; at another, a fall of 100 or 500 inches; and these two last averages may occur on the opposite flanks of a mountain-chain not more than 20 miles wide. While, therefore, the valleys in one district are widened and deepened annually, they may remain stationary in another, the superficial soil being protected from waste by a dense covering of vegetation.

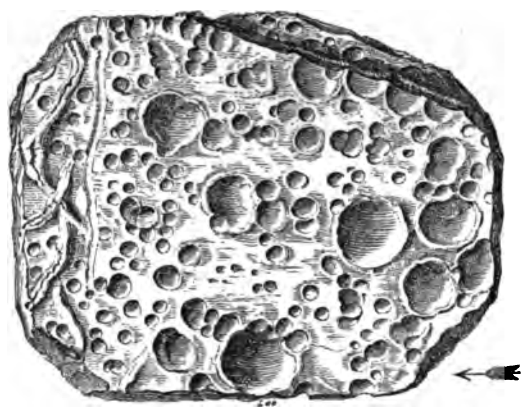
In the course of ages, the height of the land and its position relatively to the ocean will be more or less changed, and we must be careful, when speculating on the quantity of pluvial action in past ages, and the rate of the excavation of valleys, to remember, that there may have been periods of drought as well as of flood, the fall being in defect, as well as in excess, of the present annual mean.

* Hooker's Himalayan Journal, ined.

Recent rain-prints.—When examining, in 1842, the extensive mud-flats of Nova Scotia, which are exposed at low tide on the borders of the Bay of Fundy, I observed not only the foot-prints of birds which had recently passed over the mud, but also very distinct impressions of rain-drops. A peculiar combination of circumstances renders these mud-flats admirably fitted to receive and retain any markings which may happen to be made on their surface. The sediment with which the waters are charged is extremely fine, being derived from the destruction of cliffs of red sandstone and shale, and as the tides rise fifty feet and upwards, large areas are laid dry for nearly a fortnight between the spring and neap tides. In this interval the mud is baked in summer by a hot sun, so that it solidifies and becomes traversed by cracks, caused by shrinkage. Portions of the hardened mud may then be taken up and removed without injury; and a cross section of it exhibits numerous layers, formed by successive tides, each layer being usually very thin, sometimes only one-tenth of an inch thick. When a shower of rain falls, the highest portion of the mud-covered flat is usually too hard to receive any impressions; while that recently uncovered by the tide near the water's edge is too soft. Between these areas a zone occurs, almost as smooth and even as a looking-glass, on which every drop forms a cavity of circular or oval form, and, if the shower be transient, these pits retain their shape permanently, being dried by the sun, and being then too firm to be effaced by the action of the succeeding tide, which deposits upon them a new layer of mud. Hence we often find, on splitting open a slab an inch or more thick, on the upper surface of which the marks of recent rain occur, that an inferior layer, deposited during some previous rise of the tide, exhibits on its under side perfect casts of rain-prints, which stand out in relief, the moulds of the same being seen on the layer below. But in some cases, especially in the more sandy layers, the markings have been somewhat blunted by the tide, and by several rain-prints having been joined into one by a repetition of drops falling on the same spot; in which case the casts present a very irregular and blistered appearance.

The finest examples which I have seen of these rain-prints were sent to me by Dr. Webster, from Kentville, on the borders of the Bay of Mines, in Nova Scotia. They were made by a heavy shower, which fell on the 21st of July 1849, when the rise and fall of the tides were at their maximum. The impressions (see fig. 20) consist of cup-shaped or hemispherical cavities, the average size of which is from one-eighth to one-tenth of an inch across, but the largest are fully half an inch in diameter, and one-tenth of an inch deep. The depth is chiefly below the general surface or plane of stratification, but the walls of the cavity consist partly of a prominent rim of sandy mud, formed of the matter which has been forcibly expelled from the pit. All the cavities having an oval form, are deeper at one end, where they have also a higher rim.

Fig. 20.



Recent rain-prints, formed July 21, 1849, at Kentville, Bay of Fundy, Nova Scotia.
The arrow represents the direction of the shower.

and all the deep ends have the same direction, showing towards which quarter the wind was blowing. Two or more drops are sometimes seen to have interfered with each other; in which case it is usually possible to determine which drop fell last, its rim being unbroken.

On some of the specimens the winding tubular tracks of worms are seen, which have been bored just beneath the surface (see fig. 20, *left side*). They occasionally pass under the

middle of a rain-mark, having been formed subsequently. Sometimes the worms have dived beneath the surface, and then reappeared. All these appearances, both of rain-prints and worm-tracks, are of great geological interest, as their exact counterparts are seen in rocks of various ages even in formations of very high antiquity (e.g. the Carboniferous).* Small cavities, often corresponding in size to those produced by rain, are also caused by air-bubbles rising up through sand or mud; but these differ in character from rain-prints, being usually deeper than they are wide, and having their sides steeper. These, indeed, are occasionally vertical, or over-arching, the opening at the top being narrower than the pit below. In their mode, also, of mutual interference they are unlike rain-prints.†

In consequence of the effects of mountains in cooling currents of moist air, and causing the condensation of aqueous vapour in the manner above described (p. 323), it follows that in every country, as a general rule, the more elevated regions become perpetual reservoirs of water, which descends and irrigates the lower valleys and plains. The largest quantity of water is first carried to the highest region, and made to descend by steep declivities towards the sea; so that it acquires superior velocity, and removes more soil than it would do if the rain had been distributed over the plains and mountains equally in proportion to their relative areas. The water is also made by these means to pass over the greatest distances before it can regain the sea.

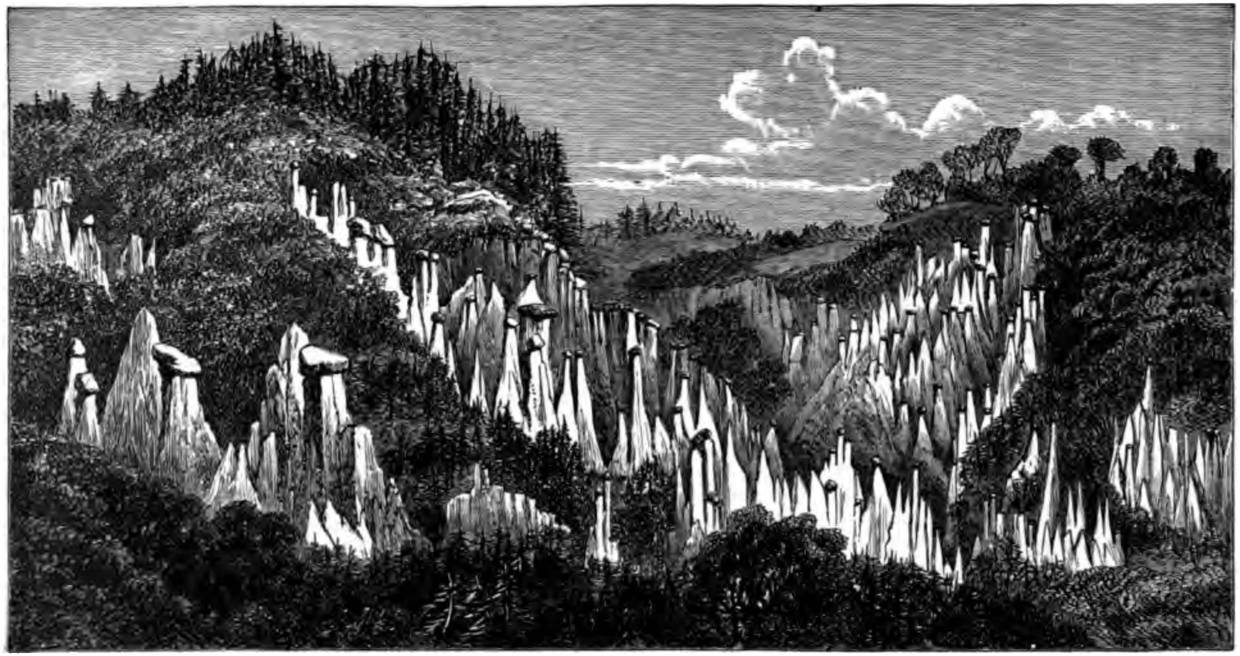
Earth-pyramids or stone-capped pillars of Botzen in the Tyrol.—It is not often that the effects of the denuding action of rain can be studied separately or as distinct from those of running water. There are, however, several cases in the Alps, and especially in the Tyrol near Botzen, which present a marked exception to this rule, where columns of indurated mud, varying in height from twenty to a hundred feet, and usually capped by a single stone, have been separated by rain from the terrace of which they once formed a part, and now

* See Elements of Geology, Index, 'Rain-prints.'

† See Lyell on recent and fossil rains. Quart. Journ. Geol. Soc. 1851, vol. vii. p. 239.

stand at various levels on the steep slopes bounding narrow valleys. Botzen is situated on the Eisack, two miles above the junction of that river with the Adige, and is 836 feet above the sea. It is in the valleys of two tributary streams which join the Eisack a short distance above Botzen, that the principal groups of pillars occur. Those nearest to the town and situated about a mile and a half to the N.E. of it, are in the ravine of the Katzenbach, elevated about 1,700 feet above Botzen; they are the most remarkable of any for their number, size, and beauty. The other pillars occur in the ravine of the Finsterbach, near Klobenstein, at the height of about 2,200 feet above Botzen, and three and a half miles N.E. of that town. These I shall describe more particularly, as the late Sir John F. W. Herschel had the kindness to enable me to give an accurate representation of them drawn by himself in 1824, by the aid of the camera lucida. I have not room to give his entire drawing, but have selected a part of it, representing the entrance of a tributary ravine into the main valley. (See Plate II.) In such smaller ravines, the same features which are seen on the boundary cliffs of the main valley are repeated, with no other difference than the diminished distance which separates the opposite banks, and the lesser size and number of the columns stretching from the top of each bank down to the brook which flows at the bottom. The breadth of the valley of the Finsterbach is between 600 and 700 feet, and its depth from 400 to 500. The pillars are many hundreds in number, and the precipitous banks from which they spring slope at angles of from 32° to 45°. The lower part of each column has usually several flat sides, so that it assumes a pyramidal instead of a conical shape. The columns consist of red unstratified mud, with pebbles and angular pieces of stone, large and small, irregularly dispersed through them. The whole mass, in short, out of which they are shaped answers in character to the moraine of a glacier, and some of the included fragments of rock have one or more of their faces smoothed or polished, furrowed and scratched, in a manner which clearly indicates their glacial origin. The stones have not their longer axes arranged in one direction, as would be

Plate II.



VIEW OF EARTH-PILLARS OF RITTEN, ON THE FINSTERBACH, NEAR BOTZEN, TYROL.

(From the original Sketch of Sir John F. W. Herschel, taken with the Camera Lucida September 11, 1821.) See p. 330.

the case if they had been deposited by running water. The matrix of hard mud has been derived evidently from the decomposition of the red porphyry, of which the whole of this country is made up, and the most numerous and largest of the capping-stones consist of the same porphyry; but blocks of granite two or three feet in diameter, which must have come from a great distance, as well as boulders of a hard chlorite rock equally foreign to the immediate neighbourhood, are also scattered sparingly through the reddish matrix. The Finsterbach, besides cutting through this unstratified mass, has excavated its channel for a depth of several yards through the underlying porphyry, or at one point through a sandstone of the Lower Trias which occasionally appears in this region. The series of geological events of which we have evidence both in this ravine and in that of the Katzenbach, will be better understood by reference to the diagram, fig. 21. First a valley *a b c* was excavated in a country consisting almost entirely of red porphyry. Secondly, this

Fig. 21.

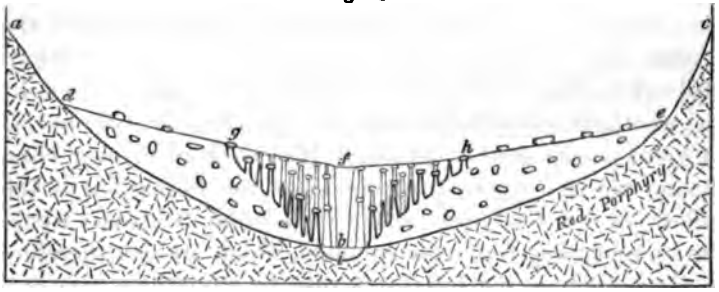


Diagram illustrative of the Formation of Earth-pillars.

a b c. Outline of original valley hollowed out of porphyry.
d b e d. Moraine left by glacier as it receded up the valley.
f. Chasm cut by torrent through the moraine before the first earth-pillars were formed.
b i. Channel of torrent excavated in porphyry below the level of the original valley.
g i h. Outline of the present valley, the earth-pillars marked by dark lines being still standing. The faint outlines between *g* and *h* represent portions of earth-pillars and their capping-stones now destroyed.

original valley was filled up in its lower part by moraine matter, *d b e d*, probably left by a large glacier as it retreated up the valley at the close of the Glacial Period.

Thirdly, the chasm *f b* was cut out of this moraine by the Finsterbach, the red mud presenting a perpendicular face towards the chasm. This mud, which is very hard and solid when dry, becomes traversed by vertical cracks after having been moistened by rain and then dried by the sun. Those portions of the surface which are protected from the direct downward action of rain by a stone or erratic block, become gradually detached and isolated near the edge of the ravine, as in the case of the incipient columns at *g* and *h*. If the capping-stone be small, it soon falls off and the column terminates upwards in a point; but if it be large, sometimes several feet or yards in diameter, the column may acquire a great height, and although tapering more and more in its upper portion where its sides have been longest exposed to the beating of the rain, it still continues to support the overhanging mass, which often looks as if poised on a point. Many of the fallen blocks, once the cappings of pillars which have disappeared, are now seen in the bed of the torrent, and their former position and the pillars on which they rested are expressed by the faint outlines given in the figure. The lower parts of some of these ancient columns still exist, because they have acquired new capping-stones by the weathering out at the surface of blocks originally buried at great depths in the moraine. Had the torrent ever risen during the long period required for the formation of the pillars, even a few yards above its present height, it would have swept away the lower columns, which are due therefore to pluvial action, not interfered with by fluviatile erosion.

If we ascend above *a* or *c*, to heights commanding a general view of the valley and moraine, the lateral terraces *d g* and *h e* look almost flat when contrasted with the precipitous cliffs *g i* and *h i*, for the latter slope at angles varying, as above stated, from 32° to 45°, whereas the terraces affording rich pastures and arable lands slope at angles varying from 10° to 16°. Here and there a large boulder or an angular erratic block is seen lying on the surface, as between *h* and *e*, which at some future time will probably become the head of a column. I measured one of the capping-stones on the left bank of the Finsterbach not far below the bridge, and

found it to be 10 feet in diameter, and the pillar which supports it 60 feet high. It seems to have owed its superior height to the large dimensions of the capping-stone, which has served as a shed to protect the indurated mud from the rain and sun. Near the edge of the cliff in the neighbourhood of this large column a wooden roof has been constructed to prevent that part of the terrace bordering the edge of the ravine along which the road passes from being split up into columns by the action of the sun and rain. The necessity of this shed attests the manner in which the denudation proceeds, and shows how its progress can be arrested. Some pillars on the Katzenbach have an elegant appearance, being perfectly round and vertically grooved or fluted. These grooves are caused by included stones which at different heights project slightly and give rise to an unequal rate of waste. In various instances such stones give origin to small lateral pillars, producing what may be called cluster columns. Both in the main valley and its tributaries the columns are arranged in rows, which descend from the edge of the terrace to the torrent, as represented between *h* and *i*; but between such parallel groups or rows are spaces devoid of columns and filled with wood, for the most part fir-trees, which form a picturesque background to the pillars when seen in profile. These intermediate spaces were probably all once occupied by columns, which have been undermined and swept away by occasional and temporary floods.

I was informed by Herr von Kaschnitz that in 1849, in cutting the road near the bridge over the Finsterbach, some trees and bushes being removed, the water was able to collect during heavy rains, and scoop out a small channel in the moraine matter, which it deepened yearly, until it undermined and removed, in the course of fifteen years, no less than twenty pillars or pyramids, and left in their place a straight empty gulley which I saw, and which in the course of time will no doubt be filled with forest trees. The natural fall of trees or landslips may sometimes afford an opportunity for such torrential action to come into play. In the absence of this, or of an earthquake, the columns, which often take centuries to form, seem capable of enduring for ages.

I have stated that some of the stones in the pillars are glaciated, although the instances are rare, and I may add that the red porphyry at several points in the district called Ritten, where the earth-pillars occur, exhibits on its surface those dome-shaped protuberances called 'roches moutonnées,' confirming the theory of the former presence of glaciers in this district. The entire absence of shells, fluviatile or terrestrial, or of bones or any organic remains in the old moraines and pillars derived from them, supports the same view. But it may be asked why such remarkable columns are so seldom met with, seeing that glacier moraines, 'till' or boulder clays, are almost universal throughout a large part of the Alps, Scotland, Scandinavia, and North America. The fact is, that incipient and imperfect columns may be seen in many districts, but it happens that near Botzen the red porphyry has given rise, by its disintegration, to dense masses of mud of a peculiarly solid, homogeneous nature, weathering with a vertical face, and having in perfection every other requisite for making pillars, namely, first the absence of stratification which, when present, usually implies the unequal destructibility of different layers; and secondly, the occurrence of numerous and often very large interspersed stones and blocks of rock.

Earth-pillars in the Canton of Valais in Switzerland.—Among many other examples of earth-pillars which I have seen in the Alps, some of the finest occur in the canton of Valais in Switzerland, though none of them form so striking a feature in the scenery as those near Botzen. Those at Stalden, in the valley of the Vispbach, are best known to tourists, and others occur near Useigne, between Sion and Evolena on the Borgne, another tributary of the Rhone, which, like the Visp, joins it on its southern or left bank.

The lower portions of both these valleys, like those of the Tyrol, before mentioned, have first been filled with moraine matter—in the case of the Borgne, more than 600 feet thick—and through the unstratified mass ravines have been cut by the action of the river, while rain has been active in widening their dimensions. In both cases the hardened mud, drift, or moraine matter, derived chiefly from the decom-

position of mica-schist, is of a whitish colour, but some included stones of serpentine, greenstone, and limestone, with surfaces distinctly glaciated, betray the glacier origin of the formation. The columns near Stalden on the Visp, about ten miles below Zermatt, were more numerous and beautiful in 1821 than they are now. This I ascertained by comparing their present condition with a drawing made in that year by Sir John Herschel. In July 1855 an earthquake inflicted much injury on the town of Visp, so that in passing through it three years afterwards, I saw rents still open in the walls of many of the houses. I then learnt that the same shock had thrown down a large part of one of the principal columns, which was 50 feet or more in height, and of which the capping-stone was 15 feet in diameter. The channel of the torrent, a small tributary of the Visp, had been deranged by landslips, and I observed that the active denudation which I saw beginning in 1857, had committed no small havoc among the pillars, in the eight years which intervened between that date and my second visit in 1865.

It is probable that few great valleys have been excavated in any part of the world, by rain and running water alone. During some part of their formation, subterranean movements have lent their aid in accelerating the process of erosion. Such movements being intermittent and often suspended for ages, and in many cases causing changes of level without any vibratory jar, their influence may easily be underrated or overlooked by geologists. At a lower point on the Vispbach, half-way between the towns of Stalden and Visp, my guide pointed out to me, in 1857, a ferruginous spring near the right bank of the river, which had never been seen until 1855, when it was laid open by a landslip, which consisted of a great mass of drift, probably moraine matter belonging to the old river terrace. A powerful rill of water flowing from this spring had already in three years scooped out a gulley, and eight years afterwards, in 1865, I found that it had cut its way much farther back, deepening and widening the small chasm, so that a vineyard which had been continuous before 1855 was then, in 1865, divided by a gap more than forty yards wide. This modern ravine was about fifteen feet deep

at its upper extremity, at an elevation of 200 feet above the Visp, and the depth increased gradually nearer the river. The shock of 1855 is believed to have shaken the Alps and the adjoining country over an area 300 miles long and 200 broad. We know not what changes of level it effected, whether the whole country was upheaved or sunk an inch, or a foot, or a yard by the event, or whether its position was unaltered. But we cannot doubt that it is to a repetition of such movements reiterated throughout indefinite ages that we owe the very existence of land above the level of the sea. We may also be assured that the shape of every district, sometimes even the minor details of its topography, are to a certain extent modified by the same agency.

Fig. 22.

Dwarf's Tower (Zwergli-Thurm) near Viesch in the canton of Valais.
From a sketch by Lady Lyell, taken Sept. 1857.*

Dwarf's Tower near Viesch.—In most of the valleys which communicate with the principal valley of the Rhone above the lake of Geneva, there is still a large remnant of that superficial drift and moraine matter which was left there at the close of the Glacial epoch. But even where we find no

* Avalanches had, in 1857, thrown down some trees, but the artist has removed others to produce the clearing here represented.

signs of the lateral valleys having been first filled up with drift to a certain height above their present streams, and then hollowed out again, it is probable that such denuding action has not been wanting. In favour of such an opinion, I may refer to two isolated stone-capped columns of hardened mud and gravel, which are to be seen in a pine forest near the village of Viesch, in a picturesque glen at the bottom of which flows a stream bearing the appropriate name of the Lawine Bach or 'Avalanche Brook.' The column which is here figured (fig. 22) occurs on the left side of the glen about 500 feet above the brook on a steep slope, the angle of which is about 45°. The fundamental rock consists of mica-schist. The height of the column is about 40 feet, its greatest diameter about 10 feet, and its irregular summit is capped by angular blocks of gneiss. Fragments of the same and of micaceous and talcose schist and pebbles of white quartz enter largely into the composition of 'the tower,' and many rocky fragments which may once have formed the capping-stones of other columns are everywhere strewed over the ground. There is a second similar pillar within 80 or 100 yards of the larger one, which is about half as high and capped by a single stone about 7 feet in diameter. The base of this smaller tower is at a higher level by about 60 feet than the summit of the larger one. I could detect no scratches or signs of glacial polishing on any of the stones which enter into the composition of these 'towers;' but this may perhaps be owing to the absence of limestone, serpentine, and greenstone rocks, which are much more favourable than gneiss for acquiring and retaining glacial markings. Avalanches of snow descend annually the steep slopes of this glen, with such force as frequently to uproot the largest pine-trees; and when we consider the destructive power of this cause and the earthquakes which have occurred again and again in the neighbourhood, we cannot but wonder that even two isolated columns have been spared to attest the former existence of a mass of matter which seems once to have levelled up the lower part of this narrow valley to a height of 500 or 600 feet above the channel of the present stream.

Action of rivers.—The pillars of Botzen before described

(p. 329), especially the tallest and most tapering of them, owe their formation to the force of separate raindrops, the water not having been able to collect into rills; but it is rarely possible to draw a clear line of demarcation between the action of

Fig. 23.

Ravine on the farm of Pomona, near Milledgeville, Georgia, as it appeared January 1846.

Excavated in twenty years, 55 feet deep, and 180 feet broad.

rain and that of running water. When travelling in Georgia and Alabama, in 1846, I saw in both these States the commencement of hundreds of valleys in places where the native forest had recently been removed. One of these newly formed gulleys or ravines is represented in the annexed woodcut,

from a drawing which I made on the spot. It occurs three miles and a half due west of Milledgeville, the capital of Georgia, and is situated on the farm of Pomona, on the direct road to Macon.*

In 1826, before the land was cleared, it had no existence: but when the trees of the forest were cut down, cracks three feet deep were caused by the sun's heat in the clay; and during the rains, a sudden rush of water through the principal crack deepened it at its lower extremity, from whence the excavating power worked backwards, till in the course of twenty years, a chasm measuring no less than 55 feet in depth, 300 yards in length, and varying in width from 20 to 180 feet, was the result. The high road has been several times turned to avoid this cavity, the enlargement of which is still proceeding, and the old line of road may be seen to have held its course directly over what is now the widest part of the ravine. In the perpendicular walls of this great chasm appear beds of clay and sand, red, white, yellow, and green, produced by the decomposition in situ of hornblendic gneiss with layers and veins of quartz, which remain entire to prove that the whole mass was once crystalline.

The termination of the cavity on the right hand in the foreground is the head or upper end of the ravine, and in almost every case, such gulleys are lengthened by the streams cutting their way backwards. The depth at the upper end is often, as in this case, considerable, and there is usually at this point, during floods, a small cascade.

I infer, from the rapidity of the denudation, which only began here after the removal of the native wood, that this spot, elevated about 600 feet above the sea, has been always covered with a dense forest, from the remote time when it first emerged from the sea.

It is, however, probable that when the granite and gneiss first rose above the waters, they consisted entirely of hard rock which had not yet been exposed to superficial decomposition and disintegration. Still we may conclude that the forest has been continuous from the time when the upper portion of these rocks began to be acted upon by rain, carbonic

* Lyell's Second Visit to the United States, 1846, vol. ii. p. 25.

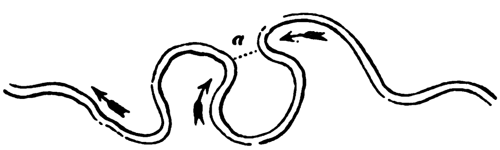
acid, the winter's frost, the intense summer heat, and other causes. I could cite other regions in Georgia and Alabama where the cutting down of the trees, which had prevented the rain from collecting into torrents and running off in sudden land-floods, has given rise to recent ravines from 70 to 80 feet deep in Tertiary and Cretaceous formations.

Sinuosities of rivers.—In proportion as such valleys are widened, sinuosities are caused by the deflection of the stream first to one side and then to the other. The unequal hardness of the materials through which the channel is eroded tends partly to give new directions to the lateral force of excavation. When by these, or by accidental shiftings of the alluvial matter in the channel, the current is made to cross its general line of descent, it eats out a curve in the opposite bank, or in the side of the hills bounding the valley, from which curve it is turned back again at an equal angle, so that it recrosses the line of descent, and gradually hollows out another curve lower down in the opposite bank, till the whole sides of the valley, or river bed, present a succession of salient and retiring angles. Among the causes of deviation from a straight course by which torrents and rivers tend in mountainous regions to widen the valleys through which they flow, may be mentioned the confluence of lateral torrents, swollen irregularly at different seasons by partial storms, and discharging at different times unequal quantities of sand, mud, and pebbles, into the main channel. The curves formed by the winding of rivers in their alluvial plains increase in magnitude in proportion to the volume of the rivers. Thus the Mississippi, about eighty miles north-west of New Orleans, near Port Hudson, makes a circuit of twenty-six miles and returns to within one mile of the point from which it set out; this occurred at Raccourci, which I visited in 1846,* and in the same year, immediately below the city of New Orleans, where the stream is about three-quarters of a mile wide, there was a bend of eighteen miles, after which the river came within five or six miles of the point from which it started. The extent of these curves depends on many conditions, especially on the nature and

* Second Visit to the United States, vol. ii. p. 193.

tenacity of the alluvial soil, often strengthened by the stems and roots of buried trees, and on the slope or fall of the river's bed.

When the tortuous flexures of a river are extremely great, the aberration from the direct line of descent may be restored by the river cutting through the isthmus which separates two neighbouring curves. Thus, in the annexed diagram, the extreme sinuosity of the river has caused it to return for a brief space in a contrary direction to its main course, so that



a peninsula is formed, and the isthmus (at *a*) is consumed on both sides by currents flowing in opposite directions. In this case an island is soon formed,—on either side of which a portion of the stream usually remains.

Transporting power of water.—In regard to the transporting power of water, we may often be surprised at the facility with which streams of a small size, and descending a slight declivity, bear along coarse sand and gravel; for we usually estimate the weight of rocks in air, and do not reflect on their comparative buoyancy when submerged in a denser fluid. The specific gravity of many rocks is not more than twice that of water, and very rarely more than thrice, so that almost all the fragments propelled by a stream have lost a third, and many of them half, of what we usually term their weight.

It has been proved by experiments, in contradiction to the theories of the earlier writers on hydrostatics, to be a universal law, regulating the motion of running water, that the velocity at the bottom of the stream is everywhere less than in any part above it, and is greatest at the surface. Also, that the superficial particles in the middle of the stream move swifter than those at the sides. This retardation of the lowest and lateral currents is produced by friction; and when the velocity is sufficiently great, the soil

composing the sides and bottom gives way. A velocity of three inches per second at the bottom is stated to be sufficient to tear up fine clay,—six inches per second, fine sand,—twelve inches per second, fine gravel,—and three feet per second, stones of the size of an egg.* Mr. Jamieson has remarked † that if the pebbly bed of a rapidly flowing river be examined, it will be found that the pebbles have a tendency to arrange themselves in the position shown in fig. 25, which is probably

Fig. 25.

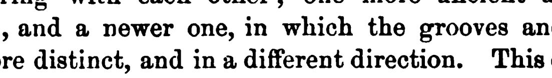
that of greatest resistance to the stream. Some sections of recent gravel in the bed of the river Dee display this arrangement, showing that the gravel had been lodged by a rapid current of water flowing down the valley.

Those peculiar inequalities or ridges on the surface of sand or sandstone which are called ripple-marks arise from the unequal force of the current by which the particles of sand are drifted along the bottom. The ridges are at right angles to the impelling force, and are steepest on their leeward side. They are formed equally by currents of wind (as on sand dunes), and under water, usually at slight depths. The following is the manner in which I once observed the motion of the air to produce this effect on a large extent of level beach, exposed at low tide near Calais. Clouds of fine white sand were blown from the neighbouring dunes, so as to cover the shore and whiten a dark level surface of sandy mud, and this fresh covering of sand was beautifully rippled. On levelling all the small ridges and furrows of this ripple over an area of several yards square, I saw them perfectly restored in about ten minutes, the general direction of the ridges being always at right angles to that of the wind. The restoration began by the appearance here and there of small detached heaps of sand, which soon lengthened and joined together, so as to form long sinuous ridges with intervening furrows. Each ridge had one side slightly inclined, and the other steep;

* Encyc. Brit. art. 'Rivers.' † Quart. Geol. Journ. vol. xvi. p. 349.

the lee side being always steep, as *b*, *c*,—*d*, *e*; the windward side a gentle slope, as *a*, *b*,—*c*, *d*, fig. 26. When a gust of wind blew with sufficient force to drive along a cloud of sand, all the ridges were seen to be in motion at once, each encroaching on the furrow before it, and, in the course of a few minutes, filling the place which the furrows had occupied. The mode of advance was by the continual drifting of grains of sand up the slopes *a b* and *c d*, which grains, when they arrived at *b* and *d*, fell over the scarps *b c* and *d e*, and were under shelter from the wind; so that they remained stationary, resting, according to their shape and momentum, on different parts of the descent, and a few only rolling to the bottom. In this manner each ridge was distinctly seen to move slowly on as often as the force of the wind augmented. Occasionally part of a ridge, advancing more rapidly than the rest, overtook the ridge immediately before it and became confounded with it, thus causing those bifurcations and

Fig. 26.



branches which are so common on the surface of sandstones of all ages. In such sandstones, as well as now on the sea-coast at low tide, we may often detect two systems of ripples interfering with each other; one more ancient and half effaced, and a newer one, in which the grooves and ridges are more distinct, and in a different direction. This crossing of two sets of ripples arises from a change in the direction of the tidal or other current, or of the wind.

It should be borne in mind that running water derives its power of rounding off the angles of hard rocks and of undermining cliffs, by setting in motion much sand, fine and coarse, and gravel, which it throws against every obstacle lying in its way. The force thus acquired by torrents in mountainous regions is more easily understood; but a question naturally arises, how the more tranquil rivers of the valleys and plains, flowing on comparatively level ground, can remove the prodigious burden which is discharged into them by their

numerous tributaries, and by what means they are enabled to convey the whole mass to the sea? If they had not this removing power, their channels would be annually choked up, and the valleys of the lower country, and plains at the base of mountain-chains, would be continually strewed over with fragments of rock and sterile sand. But this evil is prevented by a general law regulating the conduct of running water,—that two equal streams do not, when united, occupy a bed of double surface. Nay, the width of the principal river, after the junction of a tributary, sometimes remains the same as before, or is even lessened. The cause of this apparent paradox was long ago explained by the Italian writers who had studied the confluence of the Po and its feeders in the plains of Lombardy.

The addition of a smaller river augments the velocity of the main stream, often in the same proportion as it does the quantity of water. The cause of the greater velocity is, first, that after the union of two rivers the water, in place of the friction of four shores, has only that of two to surmount; 2dly, because the main body of the stream, being farther distant from the banks, flows on with less interruption; and lastly, because a greater quantity of water moving more swiftly, digs deeper into the river's bed. By this beautiful adjustment, the water which drains the interior country is made continually to occupy less room as it approaches the sea; and thus the most valuable part of our continents, the rich deltas and great alluvial plains, are prevented from being constantly under water.

River floods in Scotland, 1829.—Many remarkable illustrations of the power of running water in moving stones and heavy material were afforded by the storm and floods which occurred on the 3rd and 4th of August 1829 in Aberdeenshire and other counties in Scotland. The elements during this storm assumed all the characters which mark the tropical hurricanes; the wind blowing in sudden gusts and whirlwinds, the lightning and thunder being such as are rarely witnessed in our climate, and heavy rain falling without intermission. The floods extended almost simultaneously, and with equal violence, over that part of the north-

east of Scotland which would be cut off by two lines drawn from the head of Loch Rannoch (lat. 56·40 N., long. 4·26 W.), one towards Inverness and the other to Stonehaven. The united line of the different rivers which were flooded could not be less than from five to six hundred miles in length; and their courses were marked throughout by the destruction of bridges, roads, crops, and buildings. Sir T. D. Lauder has recorded the destruction of thirty-eight bridges, and the entire obliteration of a great number of farms and hamlets. On the Nairn, a fragment of sandstone, fourteen feet long by three feet wide and one foot thick, was carried above 200 yards down the river. Some new ravines were formed on the sides of mountains where no streams had previously flowed, and ancient river channels, which had never been filled from time immemorial, gave passage to a copious flood.*

The bridge over the Dee at Ballater consisted of five arches, having upon the whole a water-way of 260 feet. The bed of the river, on which the piers rested, was composed of rolled pieces of granite and gneiss. The bridge was built of granite, and had stood uninjured for twenty years; but the different parts were swept away in succession by the flood, and the whole mass of masonry disappeared in the bed of the river. 'The river Don,' observes Mr. Farquharson, in his account of the inundations, 'has upon my own premises forced a mass of four or five hundred tons of stones, many of them two or three hundred pounds' weight, up an inclined plane, rising six feet in eight or ten yards, and left them in a rectangular heap, about three feet deep on a flat ground:— the heap ends abruptly at its lower extremity.' †

The power even of a small rivulet, when swollen by rain, in removing heavy bodies, was exemplified in August 1827, in the College, a small stream which flows down a slight declivity from the eastern water-shed of the Cheviot Hills. Several thousand tons' weight of gravel and sand were transported to the plain of the Till, and a bridge, then in

* Sir T. D. Lauder's Account of the Great Floods in Morayshire, August 1829.

† Quarterly Journ. of Sci., &c. No. xiii. New Series, p. 331.

progress of building, was carried away, some of the arch-stones of which, weighing from half to three-quarters of a ton each, were propelled two miles down the rivulet. On the same occasion, the current tore away from the abutment of a mill-dam a large block of greenstone-porphyry, weighing nearly two tons, and transported it to the distance of a quarter of a mile. Instances are related as occurring repeatedly, in which from one to three thousand tons of gravel are, in like manner, removed by this streamlet to still greater distances in one day.*

Floods caused by landslips, 1826.—The power which running water may exert, in the lapse of ages, in widening and deepening a valley, does not so much depend on the volume and velocity of the stream usually flowing in it, as on the number and magnitude of the obstructions which have, at different periods, opposed its free passage. If a torrent, however small, be effectually dammed up, the size of the valley above the temporary barrier, and its declivity below, and not the dimensions of the torrent, will determine the violence of the débâcle. The most universal source of local deluges are landslips, slides, or avalanches, as they are sometimes called, when great masses of rock and soil, or in some cases ice and snow, are precipitated into the bed of a river, the boundary cliffs of which have been thrown down by the shock of an earthquake, or undermined by springs or other causes. Volumes might be filled with the enumeration of instances on record of these terrific catastrophes; I shall therefore select a few examples derived from regions which I have myself visited.

Two dry seasons in the White Mountains, in New Hampshire (United States), were followed by heavy rains on the 28th August 1826, when from the steep and lofty acclivities which rise abruptly on both sides of the river Saco, innumerable rocks and stones, many of sufficient size to fill a common apartment, were detached, and in their descent swept down before them, in one promiscuous and frightful ruin, forests, shrubs, and the earth which sustained them. Although there are numerous indications on the steep sides of these hills of

* Culley, Proceed. Geol. Soc. 1829.

former slides of the same kind, yet no tradition had been handed down of any similar catastrophe within the memory of man, and the growth of the forest on the very spots now devastated clearly showed that for a long interval nothing similar had occurred. One of these moving masses was afterwards found to have slid three miles, with an average breadth of a quarter of a mile. The natural excavations commenced generally in a trench a few yards in depth and a few rods in width, and descended the mountains, widening and deepening till they became vast chasms. At the base of these hollow ravines was seen a confused mass of ruins, consisting of transported earth, gravel, rocks, and trees. Forests of spruce-fir and hemlock, a kind of fir somewhat resembling our yew in foliage, were prostrated with as much ease as if they had been fields of grain; for where they disputed the ground, the torrent of mud and rock accumulated behind, till it gathered sufficient force to burst the temporary barrier.

The valleys of the Amonoosuck and Saco presented for many miles an uninterrupted scene of desolation, all the bridges being carried away, as well as those over the tributary streams. In some places, the road was excavated to the depth of from fifteen to twenty feet; in others it was covered with earth, rocks, and trees, to as great a height. The water flowed for many weeks after the flood, as densely charged with earth as it could be without being changed into mud, and marks were seen in various localities of its having risen on either side of the valley to more than twenty-five feet above its ordinary level. Many sheep and cattle were swept away, and the Willey family, nine in number, who in alarm had deserted their house, were destroyed on the banks of the Saco; seven of their mangled bodies were afterwards found near the river, buried beneath drift-wood and mountain ruins.* Eleven years after the event, the deep channels worn by the avalanches of mud and stone, and the immense heaps of boulders and blocks of granite in the river channel, still formed, says Professor Hubbard, a picturesque feature in the scenery.†

When I visited the country in 1845, eight years after

* Silliman's Journal, vol. xv. No. 2, p. 216. Jan. 1829.

† Ibid. vol. xxxiv. p. 115.

Professor Hubbard, I found the signs of devastation still very striking; I also particularly remarked that, although the surface of the bare granitic rocks had been smoothed by the passage over them of so much mud and stone, there were no continuous parallel and rectilinear furrows, nor any of the fine scratches or striæ which characterise *glacial* action. The absence of these is nowhere more clearly exemplified than in the bare rocks over which passed the great 'Willey slide' of 1826.*

But the catastrophes in the White Mountains are insignificant, when compared to those which are occasioned by earthquakes, when the boundary hills, for miles in length, are thrown down into the hollow of a valley. I shall have opportunities of alluding to inundations of this kind when treating expressly of earthquakes, and shall content myself at present with selecting an example of a flood due to a different cause.

Flood in the valley of Bagnes, 1818.—The valley of Bagnes is one of the largest of the lateral embranchments of the main valley of the Rhone, above the Lake of Geneva. Its upper portion was, in 1818, converted into a lake by the damming up of a narrow pass, by avalanches of snow and ice, precipitated from an elevated glacier into the bed of the river Dranse. In the winter season, during continued frost, scarcely any water flows in the bed of this river to preserve an open channel, so that the ice barrier remained entire until the melting of the snow in spring, when a lake was formed above, about half a league in length, which finally attained in some parts a depth of about 200 feet, and a width of about 700 feet. To prevent or lessen the mischief apprehended from the sudden bursting of the barrier, an artificial gallery, 700 feet in length, was cut through the ice, before the waters had risen to a great height. When at last they reached such an elevation as to flow through the tunnel, they dissolved the ice, and thus deepened their channel, until nearly half of the whole contents of the lake were slowly drained off. But at length, on the approach of the hot season, the central portion of the remaining mass of ice gave way with a tremendous crash, and the residue of the lake was

* See Lyell's Second Visit to the United States, vol. i. p. 69.

emptied in half an hour. In the course of their descent, the waters encountered several narrow gorges, and at each of these they rose to a great height, and then burst with new violence into the next basin, sweeping along rocks, forests, houses, bridges, and cultivated land. For the greater part of its course the flood resembled a moving mass of rock and mud, rather than of water. Some fragments of granitic rocks, of enormous magnitude, and which from their dimensions might be compared without exaggeration to houses, were torn out of a more ancient alluvium, and borne down for a quarter of a mile. One of the fragments moved was sixty paces in circumference.* The velocity of the water, in the first part of its course, was thirty-three feet per second, which diminished to six feet before it reached the Lake of Geneva, where it arrived in six hours and a half, the distance being 45 miles.†

This flood left behind it, on the plains of Martigny, thousands of trees torn up by the roots, together with the ruins of buildings. Some of the houses in that town were filled with mud up to the second story. After expanding in the plain of Martigny, it entered the Rhone, and did no further damage; but some bodies of men, who had been drowned above Martigny, were afterwards found, at the distance of about thirty miles, floating on the farther side of the Lake of Geneva, near Vevay.

The waters, on escaping from the temporary lake, intermixed with mud and rock, swept along for the first four miles at the rate of above twenty miles an hour; and M. Escher, the engineer, calculated that the flood furnished 300,000 cubic feet of water every second—an efflux which is five times greater than that of the Rhine below Basle. Now if part of the lake had not been gradually drained off, the flood would have been nearly double, approaching in volume to some of the largest rivers in Europe. It is evident, therefore, that, when we are speculating on the excavating force which a river may have exerted in any particular valley, the most important

* This block was measured by Capt. B. Hall, R.N.

† Inundation of the Val de Bagnes, in 1818, Ed. Phil. Journ., vol. i. p. 187 from memoir of M. Escher.

question is, not the volume of the existing stream, nor the present levels of its channel, nor even the nature of the rocks, but the probability of a succession of floods at some period since the time when the valley may have been first elevated above the sea.

For several months after the débâcle of 1818, the Dranse, having no settled channel, shifted its position continually from one side to the other of the valley, carrying away newly erected bridges, undermining houses, and continuing to be charged with as large a quantity of earthy matter as the fluid could hold in suspension. I visited this valley four months after the flood, and was witness to the sweeping away of a bridge, and the undermining of part of a house. The greater part of the ice-barrier was then standing, presenting vertical cliffs 150 feet high, like ravines in the lava-currents of Etna or Auvergne, where they are intersected by rivers.

Inundations, precisely similar, are recorded to have occurred at former periods in this district, and from the same cause. In 1595, for example, a lake burst, and the waters, descending with irresistible fury, destroyed the town of Martigny, where from sixty to eighty persons perished. In a similar flood, fifty years before, 140 persons were drowned.

Flood at Tivoli, 1826.—I shall conclude with one more example derived from a land of classic recollections, the ancient Tibur, and which, like all the other inundations above alluded to, occurred within the present century. The younger Pliny, it will be remembered, describes a flood on the Anio, which destroyed woods, rocks, and houses, with the most sumptuous villas and works of art.* Often for four or five centuries consecutively, this 'headlong stream,' as Horace truly called it, has remained within its bounds, and then, after so long an interval of rest, has at different periods inundated its banks again, and widened its channel. The last of these catastrophes happened 15th Nov. 1826, after excessively heavy rains, and a lively description of the event was given to me by eye-witnesses when I visited the spot in 1829. The waters appear to have been impeded by an artificial dike, by which they were separated into two parts,

* Lib. viii. Epist. 17.

a short distance above Tivoli. They broke through this dike; and, leaving the left trench dry, precipitated themselves, with their whole weight, on the right side. Here they undermined, in the course of a few hours, a high cliff, and widened the river's channel about fifteen paces. On this stood the church of St. Lucia, and about thirty-six houses of the town of Tivoli, which were all carried away, presenting, as they sank into the roaring flood, a terrific scene of destruction to the spectators on the opposite bank. As the foundations were gradually removed, buildings, some of them edifices of considerable height, were first traversed with numerous rents, which soon widened into large fissures, until at length the roofs fell in with a crash, and then the walls sunk into the river, and were hurled down the cataract below.

The destroying agency of the flood came within two hundred yards of the precipice on which the beautiful temple of Vesta stands; but fortunately this precious relic of antiquity was spared, while the wreck of modern structures was hurled down the abyss. Vesta, it will be remembered, in the heathen mythology, personified the stability of the earth; and when the Samian astronomer, Aristarchus, first taught that the earth revolved on its axis, and round the sun, he was publicly accused of impiety, for 'moving the everlasting Vesta from her place.' Playfair observed, that when Hutton ascribed instability to the earth's surface, and represented the continents which we inhabit as the theatre of incessant change and movement, his antagonists, who regarded them as unalterable, assailed him in a similar manner with accusations founded on religious prejudices.* We might appeal to the excavating power of the Anio as corroborative of one of the most controverted parts of the Huttonian theory; and if the days of omens had not gone by, the geologists who now worship Vesta might regard the catastrophe as portentous. We may, at least, recommend the modern votaries of the goddess to lose no time in making a pilgrimage to her shrine, for the next flood may not respect the temple.

Excavation of rocks by running water.—The rapidity with which even the smallest streams hollow out deep channels in

* Illustr. of Hutt. Theory, § 3, p. 147.

soft and destructible soils is remarkably exemplified in volcanic countries, where the sand and half-consolidated tuffs oppose but a slight resistance to the torrents which descend the mountain-side. After the heavy rains which followed the eruption of Vesuvius in 1824, the water flowing from the Atrio del Cavallo cut, in three days, a new chasm through strata of tuff and ejected volcanic matter, to the depth of twenty-five feet. I found the old mule road, in 1828, intersected by this new ravine.

But deep chasms may be gradually eroded through the hardest rock, by running water, charged with foreign matter. Good illustrations of this phenomenon may be seen in many valleys in Central France where the channels of rivers have been barred up by solid currents of lava, through which the streams have re-excavated a passage, often of great width and from twenty to seventy feet in depth. In these cases there are decisive proofs that neither the sea, nor any denuding wave or extraordinary body of water, has passed over the spot since the melted lava was consolidated. Every hypothesis of the intervention of sudden and violent agency is entirely excluded, because the cones of *loose* scoriæ, out of which the lavas flowed, are oftentimes at no great elevation above the rivers, and have remained undisturbéd during the whole period which has been sufficient for the hollowing out of such enormous ravines.

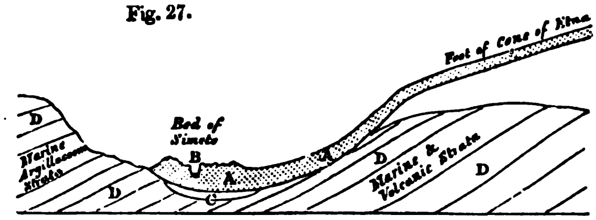
Recent excavation by the Simeto.—At the western base of Etna, a current of lava (A A, fig. 27), descending from near the summit of the great volcano, has flowed to the distance of five or six miles, and then reached the alluvial plain of the Simeto, the largest of the Sicilian rivers, which skirts the base of Etna, and falls into the sea a few miles south of Catania. The lava entered the river about three miles above the town of Aderno, and not only occupied its channel for some distance, but, crossing to the opposite side of the valley, accumulated there in a rocky mass. Gemmellaro gives the year 1603 as the date of the eruption.* The appearance of the current clearly proves that it is one of the most modern of those of Etna; for it has not been covered or crossed by

* Quadro Istorico dell' Etna, 1824.

subsequent streams or ejections, and the olive-trees which had been planted on its surface were all of small size when I examined the spot in 1828, yet they were older than the natural wood on the same lava. In the course, therefore, of about two centuries, the Simeto has eroded a passage from fifty to several hundred feet wide, and in some parts from forty to fifty feet deep.

The portion of lava cut through is in no part porous or scoriaceous, but consists of a compact homogeneous mass of hard blue rock, somewhat inferior in weight to ordinary basalt, and containing crystals of olivine and glassy felspar. The general declivity of this part of the bed of the Simeto is not considerable; but, in consequence of the unequal waste of the lava, two waterfalls occur at Passo Manzanelli,

Fig. 27.



Recent excavation of lava at the foot of Etna by the river Simeto.

each about six feet in height. Here the chasm (B, fig. 27) is about forty feet deep, and only fifty broad.

The sand and pebbles in the river-bed consist chiefly of a brown quartzose sandstone, derived from the upper country; but the materials of the volcanic rock itself must have greatly assisted the attrition. This river, like the Caltabiano on the eastern side of Etna, has not yet cut down to the ancient bed of which it was dispossessed, and of which the probable position is indicated in the above diagram (C, fig. 27).

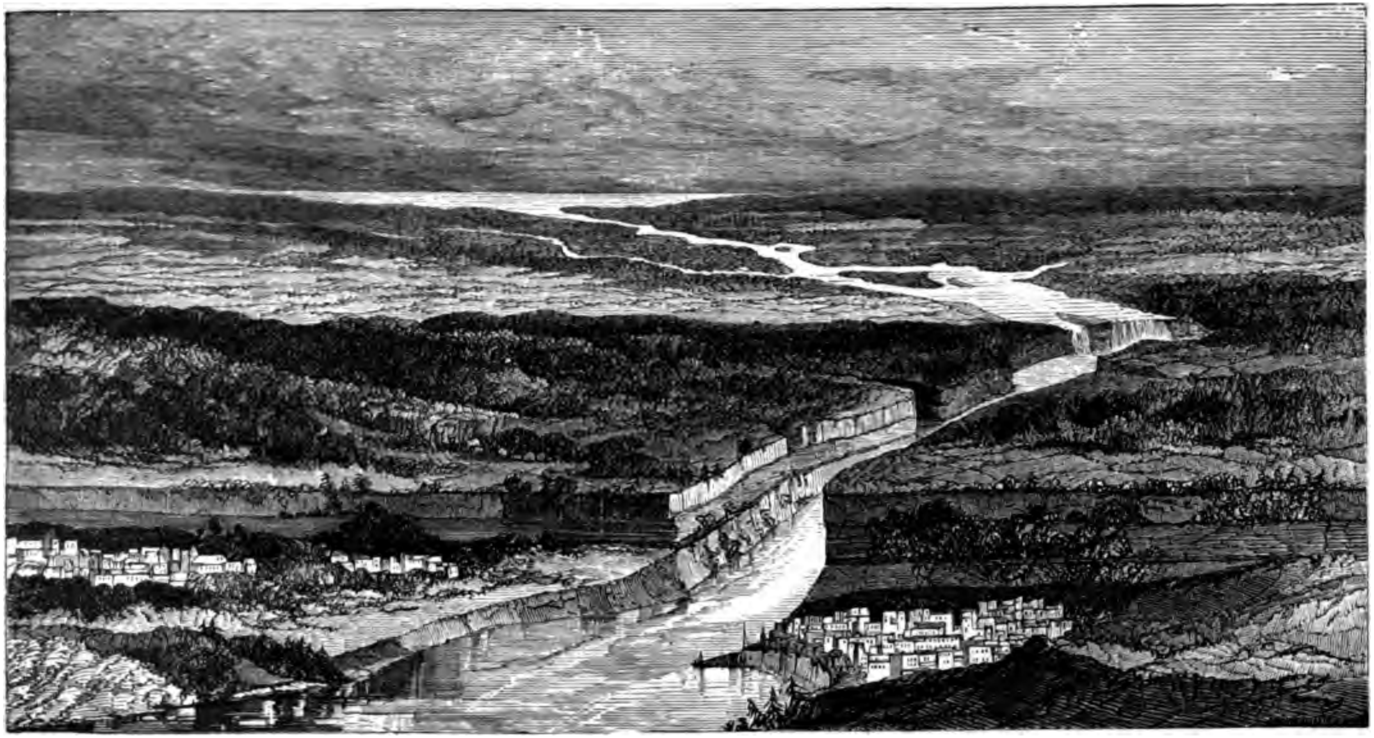
On entering the narrow ravine where the water foams down the two cataracts, we are entirely shut out from all view of the surrounding country; and a geologist who is accustomed to associate the characteristic features of the landscape with the relative age of certain rocks, can scarcely

dissuade himself from the belief that he is contemplating a scene in some rocky gorge of very ancient date. The external forms of the hard blue lava are as massive as any of the oldest trap-rocks of Scotland. The solid surface is in some parts smoothed and almost polished by attrition, and covered in others with a light-coloured lichen, which imparts to it an air of antiquity, which greatly heightens the delusion. But the moment we re-ascend the cliff the spell is broken; for we scarcely recede a few paces, before the ravine and river disappear, and we stand on the black and rugged surface of a vast current of lava, which seems unbroken, and which we can trace up nearly to the distant summit of that majestic cone which Pindar called the 'pillar of heaven,' and which still continues to send forth a fleecy wreath of vapour, reminding us that its fires are not extinct, and that it may again give out a rocky stream, wherein other scenes like that now described may present themselves to future observers.

Falls of Niagara.—The falls of Niagara afford a magnificent example of the progressive excavation of a deep valley in solid rock. That river flows over an elevated table-land, in which the basin of Lake Erie forms a depression. Where the river issues from the lake, it is nearly a mile in width, and 330 feet above the level of Lake Ontario, which is about thirty miles distant. For the first fifteen miles below Lake Erie the surrounding country, comprising Upper Canada on the west, and the state of New York on the east, is almost on a level with its banks, and nowhere more than thirty or forty feet above them.* (See Plate III.) The river being occasionally interspersed with low wooded islands, and having sometimes a width of three miles, glides along at first with a clear, smooth, and tranquil current, falling only fifteen feet in as many miles, and in this part of its course resembling an arm

* The reader will find in my Travel in North America, vol. i. ch. 2, a coloured geological map and section of the Niagara district, also a bird's-eye view of the Falls and adjacent country, coloured geologically, of which the first idea was suggested by the excellent original sketch given by Mr. Bakewell. I have referred more fully to these and to Mr. Hall's Report on the Geology of New York, as well as to the earlier writings of Hennepin and Kalm in the same work, and have speculated on the origin of the escarpment over which the falls may have been originally precipitated. Vol. i. p. 32, and vol. ii. p. 93.

Plate III.



Ideal bird's-eye view of the course of the Niagara River from Lake Erie to Queenstown, showing the ravine cut by the river between Queenstown and the Falls.) See p. 354.

of Lake Erie. But its character is afterwards entirely changed, on approaching the Rapids, where it begins to rush and foam over a rocky and uneven limestone bottom, for the space of nearly a mile, till at length it is thrown down perpendicularly 165 feet at the Falls. Here the river is divided into two sheets of water by an island called Goat Island, the larger cataract being more than a third of a mile broad, the smaller one having a breadth of 600 feet. When the water has precipitated itself into a pool of vast depth, it rushes with great velocity down the sloping bottom of a narrow chasm, for a distance of seven miles. This ravine varies from 200 to 400 yards in width from cliff to cliff: contrasting, therefore, strongly in its breadth with that of the river above. Its depth is from 200 to 300 feet, and it intersects for about seven miles the table-land before described, which terminates suddenly at Queenstown in an escarpment or long line of inland cliff facing northwards, towards Lake Ontario. The Niagara, on reaching the escarpment and issuing from the gorge, enters the flat country, which is so nearly on a level with Lake Ontario, that there is only a fall of about four feet in the seven additional miles which intervene between Queenstown and the shores of that lake.

It has long been the popular belief that the Niagara once flowed in a shallow valley across the whole platform, from the present site of the Falls to the escarpment (called the Queenstown Heights), where it is supposed that the cataract was first situated, and that the river has been slowly eating its way backwards through the rocks for the distance of seven miles. This hypothesis naturally suggests itself to every observer, who sees the narrowness of the gorge at its termination, and throughout its whole course, as far up as the Falls, above which point the river expands as before stated: The boundary cliffs of the ravine are usually perpendicular, and in many places undermined on one side by the impetuous stream. The uppermost rock of the table-land at the Falls consists of hard limestone (a member of the Silurian series), about ninety feet thick, beneath which lie soft shales of equal thickness, continually undermined by the action of the spray, which rises from the pool into which so large a

body of water is projected, and is driven violently by gusts of wind against the base of the precipice. In consequence of this action, and that of frost, the shale disintegrates and crumbles away, and portions of the incumbent rock overhang forty feet, and often when unsupported tumble down, so that the Falls do not remain absolutely stationary at the same spot, even for half a century. Accounts have come down to us, from the earliest period of observation, of the frequent destruction of these rocks, and the sudden descent of huge fragments in 1818 and 1828 is said to have shaken the adjacent country like an earthquake. The earliest travellers, Hennepin and Kalm, who in 1678 and 1751 visited the Falls, and published views of them, attest the fact, that the rocks have been suffering from dilapidation for more than a century and a half, and that some slight changes, even in the scenery of the cataract, have been brought about within that time. The idea, therefore, of perpetual and progressive waste is constantly present to the mind of every beholder; and as that part of the chasm, which has been the work of the last 150 years, resembles precisely in depth, width, and character the rest of the gorge which extends seven miles below, it is most natural to infer, that the entire ravine has been hollowed out in the same manner, by the recession of the cataract.

It must at least be conceded, that the river supplies an adequate cause for executing the whole task thus assigned to it, provided we grant sufficient time for its completion; but, as this part of the country was a wilderness till near the end of the last century, we can obtain no accurate data for estimating the exact rate at which the cataract has been receding. Mr. Bakewell, son of the eminent geologist of that name, who visited Niagara in 1829, made the first attempt to calculate, from the observations of one who had lived forty years at the Falls, and who had been the first settler there, that the cataract had during that period gone back about a yard annually. But after the most careful enquiries which I was able to make, during my visit to the spot in 1841–2, I came to the conclusion that the average of one foot a year would be a much more probable conjecture. In that case, it would have required 35,000 years for the

retreat of the Falls, from the escarpment of Queenstown to their present site. It seems by no means improbable that such a result would be no exaggeration of the truth, although we cannot assume that the retrograde movement has been uniform. An examination of the geological structure of the district, as laid open in the ravine, shows that at every step in the process of excavation, the height of the precipice, the hardness of the materials at its base, and the quantity of fallen matter to be removed, must have varied. At some points it may have receded much faster than at present, but in general its progress was probably slower, because the cataract, when it began to recede, must have had nearly twice its present height, and therefore twice the quantity of rock to remove.

From observations made by me in 1841, when I had the advantage of being accompanied by Mr. Hall, State geologist of New York, and in 1842, when I re-examined the Niagara district, I obtained geological evidence of the former existence of an old river-bed, which, I have no doubt, indicates the original channel through which the waters once flowed from the Falls to Queenstown, at the height of nearly 300 feet above the bottom of the present gorge. The geological monuments alluded to consist of patches of sand and gravel, forty feet thick, containing fluviatile shells of the genera Unio, Cyclas, Melania, &c., such as now inhabit the waters of the Niagara above the Falls. The identity of the fossil species with the recent is unquestionable, although bones of the extinct mastodon (*M. giganteus*) are associated with the same in Goat Island. These fresh-water deposits occur at several points along the cliffs bounding the ravine, so that they prove the former extension of an elevated shallow valley, four miles below the Falls, a distinct prolongation of that now occupied by the Niagara, in the elevated region intervening between Lake Erie and the Falls. Whatever theory be framed for the hollowing out of the ravine further down, or for the three miles which intervene between the whirlpool and Queenstown, it will always be necessary to suppose the former existence of a barrier of *rock*, not of loose and destructible materials, such as those composing the

drift in this district, somewhere immediately below the whirlpool. By that barrier the waters were held back for ages, when the fluviatile deposit, forty feet in thickness, and 250 feet above the present channel of the river, originated. If we are led by this evidence to admit that the cataract has cut back its way for four miles, we can have little hesitation in referring the excavation of the remaining three miles below to a like agency, the shape of the chasm being precisely similar.

There have been many speculations respecting the future recession of the Falls, and the deluge that might be occasioned by the sudden escape of the waters of Lake Erie, if the ravine should ever be prolonged sixteen miles backwards. But a more accurate knowledge of the geological succession of the rocks, brought to light by the State Survey, has satisfied every geologist that the Falls would diminish gradually in height before they travelled back two miles, and in consequence of a gentle dip of the strata to the south, the massive limestone now at the top would then be at their base, and would retard, and perhaps put an effectual stop to, the excavating process.*

* Since I visited the Falls I have repeatedly seen in the American newspapers accounts of changes caused in the outline of the cataract by the wearing away of the channel and the undermining of huge fragments of rock, which have been precipitated into the chasm below. Some of these alterations have rendered it impossible to reach a spot under the sheet of falling water to which I was led by my guide in 1841.

CHAPTER XVI.

TRANSPORTATION OF SOLID MATTER BY ICE.

CARRYING POWER OF RIVER-ICE—ROCKS ANNUALLY CONVEYED INTO THE ST. LAWRENCE BY ITS TRIBUTARIES—GROUND-ICE; ITS ORIGIN AND TRANSPORTING POWER—GLACIERS—THEORY OF THEIR DOWNWARD MOVEMENT—SMOOTHED AND GROOVED ROCKS—THE MORAINE UNSTRATIFIED—TERRACE OR BREACH FORMED BY A GLACIER-LAKE IN SWITZERLAND—ICEBERGS COVERED WITH MUD AND STONES—LIMITS OF GLACIERS AND ICEBERGS—THEIR EFFECTS ON THE BOTTOM WHEN THEY RUN AGROUND—PACKING OF COAST-ICE—BOULDERS DRIFTED BY ICE ON COAST OF LABRADOR—BLOCKS MOVED BY ICE IN THE BALTIC.

THE power of running water to carry sand, gravel, and fragments of rock to considerable distances is greatly augmented in those regions where, during some part of the year, the frost is of sufficient intensity to convert the water, either at the surface or bottom of rivers, into ice.

This subject may be considered under three different heads:—first, the effect of surface-ice and ground-ice, in enabling streams to remove gravel and stones to a distance; secondly, the action of glaciers in the transport of boulders, and in the polishing and scratching of rocks; thirdly, the floating off of portions of glaciers charged with solid matter, as icebergs, into the sea, and the drifting of coast-ice.

River-ice.—Pebbles and small pieces of rock may be seen entangled in ice, and floating annually down the Tay in Scotland, as far as the mouth of that river. Similar observations might doubtless be made respecting almost all the larger rivers of England and Scotland; but there seems reason to suspect that the principal transfer from place to place of pebbles and stones adhering to ice goes on unseen by us under water. For although the specific gravity of the compound mass may cause it to sink, it may still be very

buoyant, and easily borne along by a feeble current. The ice, moreover, melts very slowly at the bottom of running streams in winter, as the water there is often nearly at the freezing point, as will be seen from what will be said in the sequel of ground-ice.

As we travel eastward in Europe in the latitudes of Great Britain, we find the winters more severe, and the rivers more regularly frozen over. M. Lariviere relates that, being at Memel on the Baltic in 1821, when the ice of the river Niemen broke up, he saw a mass of ice thirty feet long which had descended the stream, and had been thrown ashore. In the middle of it was a triangular piece of granite, about a yard in diameter, resembling in composition the red granite of Finland.*

When rivers in the northern hemisphere flow from south to north, the ice first breaks up in the higher part of their course, and the flooded waters, bearing along large icy fragments, often arrive at parts of the stream which are still firmly frozen over. Great inundations are thus frequently occasioned by the obstructions thrown in the way of the descending waters, as in the case of the Mackenzie in North America, and the Irtish, Obi, Yenesei, Lena, and other rivers of Siberia. (See map, fig. 7, p. 180.) A partial stoppage of this kind occurred Jan. 31, 1840, in the Vistula, about a mile and a half above the city of Dantzic, where the river, choked up by packed ice, was made to take a new course over its right bank, so that it hollowed out in a few days a deep and broad channel, many leagues in length through a tract of sand-hills which were from 40 to 60 feet high.

In Canada, where the winter's cold is intense, in a latitude corresponding to that of central France, several tributaries of the St. Lawrence begin to thaw in their upper course, while they remain frozen over lower down, and thus large slabs of ice are set free and thrown upon the unbroken sheet of ice below. Then begins what is called the packing of the drifted fragments; that is to say, one slab is made to slide over another, until a vast pile is built up, and the whole, being frozen together, is urged onwards by the force of the

* Consid. sur les Blocs errat. 1829.

Plate IV.

BOULDERS DRIFTED BY ICE ON SHORES OF THE ST. LAWRENCE.

(View taken by Lieut. Bowen, from the N.E., in the Spring of 1835, at Richelieu Rapid, lat. 46 N.) See p. 365.

dammed-up waters and drift-ice. Thus propelled, it not only forces along boulders, but breaks off from cliffs, which border the rivers, huge pieces of projecting rock. By this means several buttresses of solid masonry, which, up to the year 1836, supported a wooden bridge on the St. Maurice, which falls into the St. Lawrence, near the town of Trois Rivières, lat. 46° 20′, were thrown down and conveyed by the ice into the main river; and instances have occurred at Montreal of wharfs and stone buildings, from 30 to 50 feet square, having been removed in a similar manner. We learn from Captain Bayfield that anchors laid down within high-water mark, to secure vessels hauled on shore for the winter, must be cut out of the ice on the approach of spring, or they would be carried away. In 1834, the Gulnare's bower-anchor, weighing half a ton, was transported some yards by the ice, and so firmly was it fixed, that the force of the moving ice broke a chain-cable suited for a 10-gun brig, and which had rode the Gulnare during the heaviest gales in the gulf. Had not this anchor been cut out of the ice, it would have been carried into deep water and lost.*

The scene represented in the annexed plate (Pl. IV.), from a drawing by Lieutenant Bowen, R.N., will enable the reader to comprehend the incessant changes which the transport of boulders produces annually on the low islands, shores, and bed of the St. Lawrence above Quebec. The fundamental rocks at Richelieu Rapid, situated in lat. 46° N., are limestone and slate, which are seen at low water to be covered with boulders of granite. These boulders owe their spheroidal form chiefly to weathering, or the action of frost, which causes the surface to exfoliate in concentric plates, so that all the more prominent angles are removed. At the point *a* is a cavity in the mud or sand of the beach, now filled with water, which was occupied during the preceding winter (1835) by the huge erratic *b*, a mass of granite, 70 tons' weight, found in the spring following (1836) at the distance of several feet from its former position. Many small islands are seen on the river, such as *c d*, which afford still more striking proofs of the carrying and propelling power of ice. These

* Capt. Bayfield. Geol Soc. Proceedings, vol. ii. p. 223.

islets are never under water, yet every winter ice is thrown upon them in such abundance, that it *packs* to the height of 20, and even 30 feet, bringing with it a continual supply of large stones or boulders, and carrying away others; the greatest number being deposited, according to Lieutenant Bowen, on the edge of deep water. On the island *d*, on the left of the accompanying view, a lighthouse is represented, consisting of a square wooden building, which, having no other foundation than the boulders, requires to be taken down every winter, and rebuilt on the re-opening of the river.

These effects of frost, which are so striking on the St. Lawrence above Quebec, are by no means displayed on a smaller scale below that city, where the gulf rises and falls with the tide. On the contrary, it is in the estuary, between the latitudes 47° and 49°, that the greatest quantity of gravel and boulders of large dimensions are carried down annually towards the sea. Here the frost is so intense, that a dense sheet of ice is formed at low water, which, on the rise of the tide, is lifted up, broken, and thrown in heaps on the extensive shoals which border the estuary. When the tide recedes, this packed ice is exposed to a temperature sometimes 30° below zero, which freezes together all the loose pieces of ice, as well as the granitic and other boulders. The whole of these are often swept away by a high tide, or when the river is swollen by the melting of the snow in spring. One huge block of granite, 15 feet long by 10 feet both in width and height, and estimated to contain 1,500 cubic feet, was conveyed in this manner some distance in the year 1837, its previous position being well known, as up to that time it had been used by Captain Bayfield as a mark for the surveying station.

Ground-ice.—When a current of cold air passes over the surface of a lake or stream it abstracts from it a quantity of heat, and the specific gravity of the water being thereby increased, the cooled portion sinks. This circulation may continue until the whole body of fluid has been reduced to the temperature of 40° F., after which if the cold increase, the vertical movement ceases, the water which is uppermost expands and floats over the heavier fluid below, and when it

has attained a temperature of 32° Fahr. it sets into a sheet of ice. It would seem therefore impossible, according to this law of congelation, that ice should ever form at the bottom of a river; and yet such is the fact, and many speculations have been hazarded to account for so singular a phenomenon. M. Arago is of opinion that the mechanical action of a running stream produces a circulation by which the entire body of water is mixed up together and cooled alike, and the whole being thus reduced to the freezing point, ice begins to form at the bottom for two reasons, first, because there is less motion there, and secondly, because the water is in contact with solid rock or pebbles which have a cold surface.* Even in the Thames we learn from Dr. Plott that pieces of this kind of ice, having gravel frozen on to their under side, rise up from the bottom in winter, and float on the surface. In the Siberian rivers, Weitz describes large stones as having been brought up from the river's bed in the same manner, and made to float.† It is a common remark in Russia that where the bottom of the stream is muddy, ground-ice forms less readily, and that it is produced most freely when the sky is cloudless. In that case, stones lying in the channel part with their heat by radiation more rapidly. By an admirable provision of nature, it is in those countries where river-courses are most liable to be choked up by large stones brought down from the upper country by floating ice, that ground-ice comes to the aid of the carrying power of running water.

Glaciers.—As the atmosphere becomes colder in proportion as we ascend in it, there are mountainous heights even in tropical countries where the heat of summer is insufficient to melt the winter's snow. But to reach the lower limit of perpetual snow at the equator, we must rise to an elevation of about 16,000 feet above the sea (see above, p. 251). In the Swiss Alps, in lat. 46° N., we find the line of perpetual snow descending as low as 8,500 feet above the sea, the loftier peaks of the Alpine chain being from 12,000 to 15,000

* M. Arago, Annuaire, &c. 1833; and Rev. J. Farquharson, Phil. Trans. 1835, p. 329.

† Journ. of Roy. Geograph. Soc vol. vi. p. 416.

feet high. The frozen mass augmenting from year to year would add indefinitely to the altitude of alpine summits, were it not relieved by its descent through the larger and deeper valleys to regions far below the general snow-line. To these it slowly finds its way in the form of rivers of ice called glaciers, the consolidation of which is produced by pressure, and by the congelation of water infiltered into the porous mass, which is always undergoing partial liquefaction

Fig. 28.

Glacier with medial and lateral moraines and with terminal cave.

on its surface. In a day of hot sunshine, or mild rain, innumerable rills of pure and sparkling water run in icy channels along the surface of the glaciers, which in the night shrink and come to nothing. They are often precipitated in bold cascades into deep fissures in the ice, and contribute together with springs to form torrents, which flow in tunnels at the bottom of the glaciers for many a league, and at

length issue at their extremities, from beneath beautiful caverns or arches. The waters of these streams are always densely charged with the finest mud, produced by the grinding of rock and sand under the weight of the moving mass. (See fig. 28.) The length of time during which these glaciers have existed must have been so great, and there is so much evidence of their dimensions having been formerly greater than now, that a considerable portion of the erosion, or of the widening and deepening of the valley must be attributed to ice-action. But to what extent the valleys in which the Swiss glaciers move were excavated by rivers before the valleys were filled with ice we have no positive data at present for deciding.

The length of the Swiss glaciers is sometimes between twenty and thirty miles; their width in the middle portion where they are broadest, occasionally two or three miles; their depth or thickness sometimes more than 600 feet. When they descend steep slopes and precipices, or are forced through narrow gorges, the ice is broken up, and assumes the most fantastic and picturesque forms, with lofty peaks and pinnacles, projecting above the general level. These snow-white masses are often relieved by a dark background of pines, as in the valley of Chamouni; and are not only surrounded with abundance of the wild rhododendron in full flower, but encroach still lower into the region of cultivation, and trespass on fields where the tobacco-plant is flourishing by the side of the peasant's hut.

The cause of glacier motion has during the last quarter of a century been a subject of careful investigation and much keen controversy. Although a question of physics, rather than of geology, it is too interesting to allow me to pass it by without some brief mention. De Saussure, whose 'Travels in the Alps' are full of original observations, as well as sound and comprehensive general views, conceived that the weight of the ice might be sufficient to urge it down the slope of the valley, if the sliding motion were aided by the water flowing at the bottom. For this 'gravitation theory' Charpentier, followed by Agassiz, substituted the hypothesis of dilatation. The most solid ice is always permeable to

water, and penetrated by innumerable fissures and capillary tubes, often extremely minute. These tubes imbibe the aqueous fluid during the day, which freezes, it is said, in the cold of the night, and expands while in the act of congelation. The distension of the whole mass exerts an immense force, tending to propel the glacier in the direction of least resistance—'in other words, down the valley.' This theory was opposed by Mr. Hopkins on mathematical and mechanical grounds, in several able papers. Among other objections, he pointed out that the friction of so enormous a body as a glacier on its bed is so great, that the vertical direction would always be that of least resistance, and if a considerable distension of the mass should take place, by the action of freezing, it would tend to increase its thickness, rather than accelerate its downward progress. He also contended (and his arguments were illustrated by many ingenious experiments) that a glacier can move along an extremely slight slope, solely by the influence of gravitation, owing to the constant dissolution of ice in contact with the rocky bottom, and the number of separate fragments into which the glacier is divided by fissures, so that freedom of motion is imparted to its several parts somewhat resembling that of an imperfect fluid. To this view Principal James D. Forbes objected that gravitation would not supply an adequate cause for the sliding of solid ice down slopes having an inclination of no more than four or five degrees, still less would it explain how the glacier advances where the channel expands and contracts. The Mer de Glace in Chamouni, for example, after being 2,000 yards wide, passes through a strait only 900 yards in width. Such a gorge, it is contended, would be choked up by the advance of any solid mass, even if it be broken up into numerous fragments. The same acute observer remarked, that water in the fissures and pores of glaciers cannot, and does not, part with its latent heat, so as to freeze every night to a great depth, or far in the interior of the mass. Had the dilatation theory been true, the chief motion of the glacier would have occurred about sunset, when the freezing of the water must be greatest, and it had, in fact, been at first assumed by those who favoured that hypothesis,

that the mass moved faster at the sides, where the melting of ice was promoted by the sun's heat, reflected from boundary precipices.

Agassiz appears to have been the first to commence, in 1841, aided by a skilful engineer, M. Escher von der Linth, a series of exact measurements to ascertain the laws of glacier motion, and he soon discovered, contrary to his preconceived notions, that the stream of ice moved more slowly at the sides than at the centre, and faster in the middle region of the glacier than at its extremity.* Principal J. D. Forbes, who had joined Professor Agassiz during his earlier investigations in the Alps, undertook himself an independent series of experiments, which he followed up with great perseverance, to determine the laws of glacier motion. These he found to agree very closely with the laws governing the course of rivers, their progress being greater in the centre than at the sides, and more rapid at the surface than at the bottom. This fact was verified by carefully fixing a great number of marks in the ice, arranged in a straight line, which gradually assumed a beautiful curve, the middle part pointing down the glacier, and showing a velocity there, double or treble that of the lateral parts.† He ascertained that the rate of advance by night was nearly the same as by day, and that even the hourly march of the icy stream could be detected, although the progress might not amount to more than six or seven inches in twelve hours. By the incessant though invisible advance of the marks placed on the ice, 'time,' says Mr. Forbes, 'was marked out as by a shadow on a dial, and the unequivocal evidence which I obtained, that even whilst walking on a glacier we are, day by day, and hour by hour, imperceptibly carried on by the resistless flow of the icy stream, filled me with admiration.'‡ In order to explain this remarkable regularity of motion, and its obedience to laws so strictly analogous to those of fluids, the same writer proposed the theory, the germ of which was first hinted by Rendu, that the ice, instead of being solid and

* See Système glaciaire, by Agassiz, Guyot, and Desor, pp. 436, 437, 445.

† J. D. Forbes. 8th Letter on Glaciers, Aug. 1844.

‡ J. D. Forbes. Travels in the Alps, 1st ed. p. 133.

compact, is a viscous or plastic body, capable of yielding to great pressure, and the more so in proportion as its temperature is higher, or as it approaches more nearly to the melting point. He endeavoured to show that this hypothesis would account for many complicated phenomena, especially for a ribboned or veined structure which is everywhere observable in the ice, and might be produced by lines of discontinuity, arising from the different rates at which the various portions of the semi-rigid glacier advance and pass each other. Many examples were adduced to prove that a glacier can model itself to the form of the ground over which it is forced, exactly as would happen if it possessed a certain ductility, and this power of yielding under intense pressure was supposed not to be irreconcilable with the idea of the ice being sufficiently compact to break into fragments when the strain upon its parts is excessive; as where the glacier turns a sharp angle, or descends upon a rapid or convex slope. The increased velocity in summer was attributed partly to the greater plasticity of the ice, when not exposed to intense cold, and partly to the hydrostatic pressure of the water in the capillary tubes, which imbibe more of this liquid in the hot season.

Mr. Hopkins, on the other hand, assuming the ice to be a rigid, not a viscous mass, attributed the more rapid motions in the centre to the unequal rate at which the broad stripes of ice, intervening between longitudinal fissures, advance; but besides that there are parts of the glacier where no such fissures exist, such a mode of progression, said Mr. Forbes, would cause the borders of large transverse rents, or 'crevasses,' to be jagged like a saw, instead of being perfectly even and straight-edged.* An experiment made in 1853 by Mr. Christie, secretary to the Royal Society, demonstrated that ice, under great pressure, possesses a sufficient degree of moulding and self-adapting power to allow it to be acted upon, as if it were a pasty or viscous substance. A hollow

* See Mr. Hopkins on Motion of Glaciers, Cambridge Phil. Trans. 1844, and Phil. Mag. 1845. Some of the concessions of this author as to a certain plasticity in the mass, made the difference between him and Principal Forbes little more than one of degree. (For the summary of Principal J. D. Forbes' views, see Phil. Trans. 1846, pt. 2.)

shell of iron an inch and a half thick, the interior being ten inches in diameter, was filled with water, in the course of a severe winter, and exposed to the frost, with the fuze-hole uppermost. A portion of the water expanded in freezing, so as to protrude a cylinder of ice from the fuze-hole; and this cylinder continued to grow inch by inch in proportion as the central nucleus of water froze. As we cannot doubt that an outer shell of ice is first formed, and then another within, the continued rise of the column through the fuze-hole must proceed from the squeezing of successive shells of ice, concentrically formed, through the narrow orifice; and yet the protruded cylinder consisted of entire, and not of fragmentary ice.*

When the hypothesis of viscosity had been so admirably worked out and illustrated by Forbes as to appear to be firmly established, Dr. Tyndall objected that it would account for a part only of the facts. Ice, he admitted, deports itself as a viscous body in cases where it is subjected to pressure alone, but when tension comes into play the analogy with a viscous body ceases. 'The glacier widens, bends, and narrows, and its centre moves more quickly than its sides. A viscous mass would undoubtedly do the same. But the most delicate experiments on the capacity of ice to yield to strain,—to stretch out like treacle, honey, or tar,—have failed to detect this stretching power. Is there,' he asks, 'then, any other physical quality to which the power of accommodation possessed by glacier-ice may be referred?'†

Faraday had called attention, in 1850, to the fact that if two pieces of ice having throughout a temperature of 32° F., and each melting at its surface, are made to touch each other, they will freeze together at the points of contact. This effect will take place even if the two pieces are plunged into hot water and held together for half a minute. In virtue of this property, which has been called 'regelation,' a mass of ice crushed into fragments may be squeezed forcibly into a mould, and then subjected to hydraulic pressure so that the parts are brought into still closer proximity. It is

* This experiment is cited by Mr. Forbes, Phil. Trans. 1846, p. 206.

† Tyndall, Heat as a Mode of Motion, 1863, pp. 185, 189.

then converted into a coherent cake of ice. All the touching surfaces of the icy fragments are cemented together by regelation, by virtue of which property the substance may be made to take any shape we please. 'It is easy therefore,' says Tyndall, 'to understand how a substance so endowed can be squeezed through the gorges of the Alps—can bend so as to accommodate itself to the flexures of the Alpine valleys, and can permit of a differential motion of its parts, without at the same time possessing a sensible trace of viscosity.'

The agency of glaciers in producing permanent geological changes consists partly in their power of transporting gravel, sand, and huge stones to great distances, and partly in the smoothing, polishing, and scoring of their rocky channels, and the boundary walls of the valleys through which they pass. At the foot of every steep cliff or precipice in high Alpine regions, a talus is seen of rocky fragments detached by the alternate action of frost and thaw. If these loose masses, instead of accumulating on a stationary base, happen to fall upon a glacier, they will move along with it, and, in place of a single heap, they will form in the course of years a long stream of blocks. If a glacier be twenty miles long, and its annual progression about 500 feet, it will require about two centuries for a block thus lodged upon its surface to travel down from the higher to the lower regions, or to the extremity of the icy mass. This terminal point remains usually unchanged from year to year, although every part of the ice is in motion, because the liquefaction by heat is just sufficient to balance the onward movement of the glacier, which may be compared to an endless file of soldiers, pouring into a breach, and shot down as fast as they advance.

The stones carried along on the ice are called in Switzerland the 'moraines' of the glacier. There is always one line of blocks on each side or edge of the icy stream, and often several in the middle, where they are arranged in long ridges on mounds of snow and ice, often several yards high. The reason of their projecting above the general level is the non-liquefaction of the ice in those parts of the surface of the glacier which are protected from the rays of the sun, or the

action of the wind, by the covering of earth, sand, and stones. (See fig. 28, p. 364.) The cause of 'medial moraines' was first explained by Agassiz, who referred them to the confluence of tributary glaciers.* Upon the union of two streams of ice, the right lateral moraine of one of the streams comes in contact with the left lateral moraine of the other, and they afterwards move on together, in the centre, if the confluent glaciers are equal in size, or nearer to one side if unequal.

Fragments of stone and sand, which fall through crevasses in the ice and get interposed between the moving glacier and the fundamental rock, are pushed along so as to have their angles more or less worn off, and many of them are entirely ground down into mud. Some blocks are pushed along between the ice and the steep boundary rocks of the valley, and these, like the rocky channel at the bottom of the valley, often become smoothed and polished, and scored with parallel furrows, or with lines and scratches produced by hard minerals such as crystals of quartz, which act like the diamond upon glass.† This effect is perfectly different from that caused by the action of water, or a muddy torrent forcing along heavy stones; for these not being held fast like fragments of rock in ice, and not being pushed along under great pressure, cannot scoop out long rectilinear furrows or grooves parallel to each other.‡ The discovery of such markings at various heights far above the surface of the existing glaciers, and for miles beyond their present terminations, affords geological evidence of the former extension of the ice beyond its present limits in Switzerland and other countries.

The moraine of the glacier, observes Charpentier, is entirely devoid of stratification, for there has been no sorting of the materials, as in the case of sand, mud, and pebbles, when deposited by running water. The ice transports indifferently, and to the same spots, the heaviest blocks and the finest particles, mingling all together, and leaving them in one confused and promiscuous heap wherever it melts.§

* Études sur les Glaciers, 1840.

† See Elements of Geol. ch. xi.

‡ Agassiz, Jam. Ed. New Phil. Journ. No. 54, p. 388.

§ Charpentier, Ann. des Mines, tom. viii.; see also Papers by MM. Venetz and Agassiz.

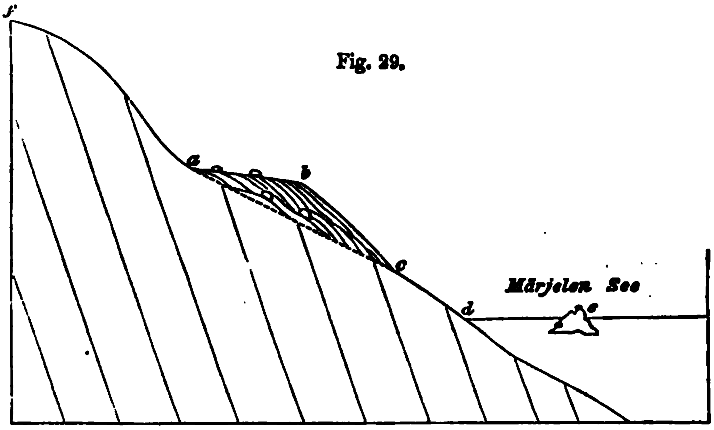
In the foreground of the woodcut, fig. 28, p. 364, some dome-shaped masses of smoothed rock are represented, called in Switzerland 'roches moutonnées,' for they are compared to the backs of sheep which are lying down. These owe their rounded and smooth outline to the action of the glacier when it was more in advance, the inequalities of the hard rock having been planed and rubbed off, in the manner before described. In 1857 I was able to pass for some distance under the terminal arch of the great glacier of the Viesch, a tributary of the Upper Rhone. It was in autumn (Sept. 1st), and during the preceding summer the glacier had retreated many yards. Under the arch on one side was a floor of white granite streaked, not only with straight furrows freshly made, but also with many parallel black lines which had been ruled by fragments of soft, dark blue slate, fixed in the moving ice. According as the impinging stones had been harder or softer than the floor over which they grated they had either cut lasting rectilinear furrows in the rock or had merely left superficial black markings which the glacier torrent of the ensuing winter would speedily wash away.

Glacier lake—Märjelen See.—There are several instances in the Himalaya where glaciers descending from lateral valleys cross the main valley and convert a portion of it into a lake by damming up the river. The converse of this may sometimes happen, as where a glacier descending the main valley causes a lake by blocking up the lower end of a tributary valley. An example of this occurs in the Swiss Alps, a few miles above Brieg, in the Canton of Valais, where the great glacier of Aletsch gives rise in this way to a small lake called the Märjelen See, which, after lasting for periods varying from three to five years, is periodically drained by changes which take place in the internal structure of the glacier. Rents or 'crevasses' in the ice open and give passage to the waters, which escape in a few hours, producing destructive inundations in the country below. Nothing is then left but a small stream flowing at the bottom of the basin, which last, after an interval of about a year, is again filled, the water rising to its old level, and

so continuing for several years. This old level is determined, not by the height of the glacier-dam, but by that of a watershed, or col, which separates the Märjelen See from the adjoining valley of the Viesch glacier, which lies to the eastward. (See fig. 30, p. 374.) The Märjelen See was about two miles in circumference when I visited it in August 1865, and about forty feet below its normal level; for in the month of June in the preceding year, it had undergone one of its periodical drainages, and the basin had not yet been filled again. Such a state of things gave me an opportunity of examining a point of great geological interest, namely, the form and structure of a large terrace or line of beach which encircles the lake basin all round its margin, and which constitutes its shore when it is full, and when its surplus waters flow over to the Viesch valley. I satisfied myself that this terrace is a counterpart of one of those ancient shelves or parallel roads, as they are called, of Glen Roy in Scotland, which, as Agassiz first suggested, were probably formed on the edge of lakes dammed up by ice, which may have existed in the Glacial Period in Scotland. The terrace or beach of the Märjelen See consists chiefly of sand and small pebbles of quartz, with stones of mica-schist, gneiss, granite, and a hornblende rock, most of them angular and from a few inches to four feet in diameter. The sand was stratified, but I could find no organic remains in it. The width of the shelf, *a b* (see fig. 29), is about sixteen paces, and its slope varies from angles of 5° to 15°. The slope from *b* to *c*, which is under water when the lake is full, has an angle of 29°. The vertical height of the upper part of the shelf *a*, above the lowest subaqueous portion, *c*, is thirty-six feet. The fundamental rock consists of highly inclined mica-schist. The materials of the terrace or shelf are such as might have been derived chiefly from the waste of the steeply sloping flanks of the boundary heights *f a*, but they consist, no doubt, in part of fragments of rock, stranded by miniature icebergs, such as *e* (fig. 29), of which many are continually detached from the barrier of ice at the lower end of the lake. I saw many of these bergs floating on the lake, with stones and mud frozen into them, parts of the moraine

of the Aletsch Glacier, and which may have come from distant mountains. The icy fragments were melting, and

Fig. 29.

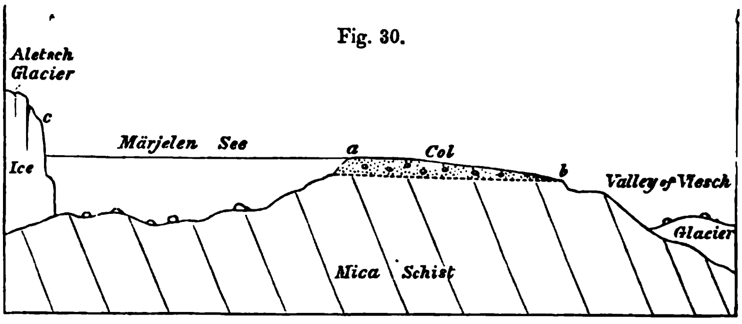


Section of the glacier lake called the Märjelen See.

a b c. Terrace of detrital matter formed on the margin of the lake when full.
d. Surface of lake 40 feet below its usual level.
e. Mass of floating ice with included stones detached from the dam.
f. Boundary hill composed of mica-schist.

as their centres of gravity changed, they frequently capsized. The materials thus transported must be strewed in part over the whole bottom of the lake, but by far the greater number

Fig. 30.



position of the lake called Märjelen See and the Valley of Viesch.

a b. Col or dividing ridge between the two valleys.
c. Vertical cliff of ice forming the dam.

must be stranded on the shore when the lake is full, or in its normal condition. In fig. 30 the position of the lake

dammed up by the Aletsch Glacier, and its relation to the adjoining valley of Viesch, are shown. The col or lowest depression between the two valleys is seen at *a b*, and along this level the stream issuing from the Märjelen See, at *a*, flows habitually to *b*, where it falls in a cascade over the rocks, on its way to the valley of Viesch. In passing from *a* to *b*, it cuts through ancient moraine matter, and its channel has been deepened artificially several feet, with a view of preventing the Märjelen See from rising to its full height, thereby lessening the magnitude of the floods caused by the bursting of the icy dam. The Mayor or Castellan of Viesch showed me an old document, from which I learnt that towards the end of the 17th century (1683) the government of the Canton of Valais were busy with a scheme for draining the Märjelen See, and diminishing the volume of its periodical inundations. This record is valuable, as teaching us that both the ordinary and exceptional condition of the lake, about two centuries ago, were the same as now.

Those geologists who have contended that the old beaches or parallel roads of Lochaber in Scotland were formed on the margins of sheets of water blocked up by ice, have sometimes been met with the objection that we can hardly imagine such a blockage to be permanent, or to retain the water steadily at the same level. Now, as to the constancy of the level, it is admitted that each of the Scotch shelves coincides with a watershed or col dividing the glen in which the shelf occurs, from an adjoining glen. Provided the dam of ice be higher than this watershed, it may evidently vary in magnitude to any amount without in any way affecting the level of the beach or marginal terrace of detrital matter. But we also learn from the Märjelen See, that even if the ice-dam periodically gives way, and is renewed after months or years, it will not, if the physical geography of the district remains unaltered, affect the constancy of the level at which the principal beach or road is formed.*

* In the 'Antiquity of Man,' I have given a description of the 'parallel roads' alluded to, and have referred to the numerous authors on the subject, concluding with the papers of Mr. Jamieson, of Ellon, in support of the glacier-lake theory.

Icebergs.—In countries situate in high northern latitudes, like Spitzbergen, between 70° and 80° N., glaciers, loaded with mud and rock, descend to the sea, and there huge fragments of them float off and become icebergs. Scoresby counted 500 of these bergs drifting along in latitudes 69° and 70° N., which rose above the surface from the height of 100 to 200 feet, and measured from a few yards to a mile in circumference.* Many of them were loaded with beds of earth and rock of such thickness, that the weight was conjectured to be from 50,000 to 100,000 tons. Specimens of the rocks were obtained, and among them were granite, gneiss, mica-schist, clay-slate, granular felspar, and greenstone. Such bergs must be of great magnitude, because the mass of ice below the level of the water is about eight times greater than that above. Wherever they are dissolved, it is evident that the 'moraine' will fall to the bottom of the sea. In this manner may submarine valleys, mountains, and platforms become strewed over with gravel, sand, mud, and scattered blocks of foreign rock, of a nature perfectly dissimilar from all in the vicinity, and which may have been transported across unfathomable abysses. If the bergs happen to melt in still water, so that the earthy and stony materials may fall tranquilly to the bottom, the deposit will probably be unstratified, like the terminal moraine of a glacier; but whenever the materials are under the influence of a current of water as they fall, they will be sorted and arranged according to their relative weight and size, and therefore more or less perfectly stratified.

We have already stated that some ice-islands have been known to drift from Baffin's Bay to the latitude of the Azores, and from the South Pole to the immediate neighbourhood of the Cape of Good Hope, so that the area over which the effects of moving ice may be experienced comprehends a large portion of the globe.

In the account given by Messrs. Dease and Simpson, of their arctic discoveries in 1838, we learn that in lat. 71° N., long. 156° W., they found 'a long low spit, named Point Barrow, composed of gravel and coarse sand, in some parts

* Voyage in 1822, p. 233.

more than a quarter of a mile broad, which the pressure of the ice had forced up into numerous mounds, that, viewed from a distance, assumed the appearance of huge boulder rocks.'*

The fact is important, as showing how masses of drift ice, when stranding on submarine banks, may exert a lateral pressure capable of bending and dislocating any yielding strata of gravel, sand, or mud. The banks on which icebergs occasionally run aground between Baffin's Bay and Newfoundand, are many hundred feet under water, and the force with which they are struck will depend not so much on the velocity as the momentum of the floating ice-islands. The same berg is often carried away by a change of wind, and then driven back again upon the same bank, or it is made to rise and fall by the waves of the ocean, so that it may alternately strike the bottom with its whole weight, and then be lifted up again, until it has deranged the superficial beds over a wide area. In this manner the geologist may account, perhaps, for the circumstance that in Scandinavia, Scotland, and other countries where erratics are met with, the beds of sand, loam, and gravel are often vertical, bent, and contorted into the most complicated folds, while the underlying strata, although composed of equally pliant materials, are horizontal. But some of these curvatures of loose strata may also have been due to repeated alternations of layers of gravel and sand, ice and snow, the melting of the latter having caused the intercalated beds of indestructible matter to assume their present anomalous position.

There can be little doubt that icebergs must often break off the peaks and projecting points of submarine mountains, and must grate upon and polish their surface, furrowing or scratching them, and reducing them to dome-shaped masses, in precisely the same way as we have seen that glaciers act on the solid rocks over which they are propelled.†

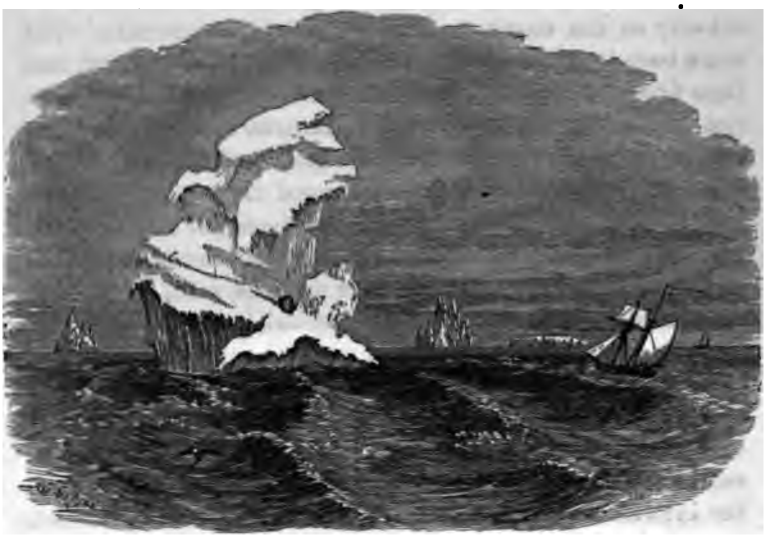
We learn from Von Buch that the most southern point on

* Journ. of Roy. Geograph. Soc. vol. viii. p. 221.

† In my Travels in N. America, pp. 19, 23, &c., and Second Visit to the U. S., vol. i. ch. 2, also in my Elements of Geology, 6th ed. p. 144, and Student's Elements, p. 150, a more full account of the action of floating ice and coast-ice, and its bearing on geology, will be found.

the continent of Europe at which a glacier comes down to the sea is in Norway, in lat. 67° N.* But Mr. Darwin has shown that they extend to the sea, in South America, in latitudes more than 20° nearer the equator than in Europe. Thus in Chili, for example, they occur, as before stated, in the Gulf of Penas, in the latitude of central France; and in Sir George Eyre's Sound, in the latitude of Paris, they give origin to icebergs, which were seen in 1834 carrying angular pieces of granite, and stranding them in fiords, where the

Fig. 31.



Iceberg seen 1,400 miles E.N.E. of Enderby's Land.
Sketched by Mr. John M'Nab.†

shores were composed of clay-slate.‡ A certain proportion, however, of the ice-islands seen floating both in the northern and southern hemispheres, are probably not generated by glaciers, but rather by the accumulation of coast-ice. When the sea freezes at the base of a lofty precipice, the sheet of ice is prevented from adhering to the land by the rise and fall of the tide. Nevertheless, it often continues on shore at the

* Travels in Norway.

† Journ. of Roy. Geograph. Soc. vol. ix. p. 526.

‡ Darwin's Journal, p. 283.

foot of the cliff, and receives accessions of drift snow blown from the land. Under the weight of this snow the ice sinks slowly if the water be deep, and the snow is generally converted into ice by partial liquefaction and re-congelation. In this manner, islands of ice, of great thickness and many leagues in length, originate, and are eventually blown out to sea by off-shore winds. In their interior are enclosed many fragments of stone which have fallen upon them from overhanging cliffs during their formation. Such floating icebergs are commonly flat-topped, but their lower portions are liable to melt in latitudes where the ocean at a moderate depth is usually warmer than the surface water and the air. Hence their centre of gravity changes continually, and they turn over and assume very irregular shapes.

In a voyage of discovery made in the antarctic regions in 1839, a dark-coloured angular mass of rock was seen imbedded in an iceberg, drifting along in mid ocean in lat. 61° S. That part of the rock which was visible was about 12 feet in height, and from 5 to 6 in width, but the dark colour of the surrounding ice indicated that much more of the stone was concealed. The annexed drawing (fig. 31) was made by Mr. McNab, when the vessel was a quarter of a mile distant.* This iceberg, one of many observed at sea on the same day, was between 250 and 300 feet high, and was no less than 1,400 miles from any certainly known land. It is exceedingly improbable, says Mr. Darwin in his notice of this phenomenon, that any land will hereafter be discovered within 100 miles of the spot, and it must be remembered that the erratic was still firmly fixed in ice, and may have sailed for many a league farther before it dropped to the bottom.†

Captain Sir James Ross, in his antarctic voyage, in 1841–2 and 3, saw multitudes of icebergs transporting stones and rocks of various sizes, with frozen mud, in high southern latitudes. His companion, Dr. J. Hooker, informs me that he came to the conclusion, that most of the southern icebergs have stones in them, although they are usually concealed from view by the quantity of snow which falls upon them.

* Journ. of Roy. Geograph. Soc. vol. ix. p. 526. † Ibid.

Retransportation of ancient glacial boulders.—The borders of the Canadian lakes, and the beds of the torrents and rivers, about 1,000 in number, which flow into those lakes, are strewn with boulders and erratic blocks which are either distinctly glaciated, or polished and striated in such a way as to imply that they belong to the ancient period of intense cold, when the country was covered with glaciers. Every year great numbers of these blocks are lifted up by ground-ice from the bottom (see p. 362) when the river is frozen over, and on the breaking up of the ice they are carried down by the river into the lake, and drifted for a hundred miles or more in all directions by the wind, and fall to the bottom, so that at some future period geologists not on their guard might refer the glaciation of these blocks to the present era instead of the remote period at which they acquired their superficial ice-markings.*

Coast-ice.—It appears, then, that large stones, mud, and gravel are carried down by the ice of rivers, estuaries, and glaciers, into the sea, where the tides and currents of the ocean, aided by the wind, may cause them to drift for hundreds of miles from the place of their origin. But we have not yet considered the transporting agency of coast-ice, which is often very active on the shores of the ocean far from the points where rivers enter.

The saline matter which sea-water holds in solution prevents its congelation except where the most intense cold prevails. But the drifting of the snow from the land often renders the surface water brackish near the coast, so that a sheet of ice is readily formed there, and by this means a large quantity of gravel is frequently conveyed from place to place, and heavy boulders also, when the coast-ice is packed into dense masses. Both the large and small stones, thus conveyed, usually travel in one direction like shingle-beaches, and this was observed to take place on the coast of Labrador and Gulf of St. Lawrence, between the latitudes 50° and 60° N., by Captain Bayfield during his survey in 1839. The line of coast alluded to is strewed over for a distance of no less than 700 miles with ice-borne boulders, often six feet in

* Letter of Henry Landor, Canada, to C. Darwin, March 10, 1869.

diameter, which are for the most part on their way from north to south, or in the direction of the prevailing current. Some points on this coast have been observed to be occasionally deserted, and then again at another season thickly bestrewed with erratics.

The accompanying drawing (fig. 32), for which I am indebted to Lieut. Bowen, R.N., represents the ordinary appearance of the Labrador coast, between the latitudes of 50° and 60° N. Countless blocks, chiefly granitic, and of various sizes, are seen lying between high and low water mark. Captain Bayfield saw similar masses carried by ice

Fig. 32.

Boulders, chiefly of granite, stranded by ice on the coast of Labrador, between lat. 50° and 60° N. (Lieut. Bowen, R.N.)

through the Straits of Belle Isle, between Newfoundland and the American continent, which he conceives may have travelled in the course of years from Baffin's Bay, a distance which may be compared in our hemisphere to the drifting of erratics from Lapland and Iceland as far south as Germany, France, and England.

It may be asked, in what manner have these erratic blocks been originally detached? We may answer that some have fallen from precipitous cliffs, others have been lifted up from the bottom of the sea, adhering by their tops to the ice, while others have been brought down by rivers and glaciers.

The erratics of North America are sometimes angular, but most of them have acquired a spheroidal form, either by friction or decomposition. The granite of Canada, as before remarked (p. 361), has a tendency to exfoliation, and scales off in concentric coats when exposed to the spray of the sea during severe frosts. The range of the thermometer in that country usually exceeds, in the course of the year, 100°, and sometimes 120° F.; and to prevent the granite used in the buildings of Quebec from peeling off in winter, it is necessary to oil and paint the squared stones.

In parts of the Baltic, such as the Gulf of Bothnia, where the quantity of salt in the water amounts in general to one fourth only of that in the ocean, the entire surface freezes over in winter to the depth of 5 or 6 feet. Stones are thus frozen in, and afterwards lifted up about 3 feet perpendicularly on the melting of the snow in summer, and then carried by floating ice-islands to great distances. Professor Von Baer states, in a communication on this subject to the Academy of St. Petersburg, that a block of granite, weighing a million of pounds, was carried by ice during the winter of 1837–8 from Finland to the island of Hockland, and two other huge blocks were transported about the years 1806 and 1814 by packed ice on the south coast of Finland, according to the testimony of the pilots and inhabitants, one block having travelled about a quarter of a mile, and lying about 18 feet above the level of the sea.*

More recently Dr. Forchhammer has shown that in the Sound, the Great Belt, and other places near the entrance of the Baltic, ground-ice forms plentifully at the bottom, and then rises to the surface, charged with sand, gravel, stones, and seaweed. Sheets of ice, also, with included boulders, are driven up on the coast during storms, and 'packed' to a height of 50 feet. The Danish professor relates a striking fact to prove that large quantities of rocky fragments are annually carried by ice out of the Baltic. 'In the year 1807,' he says, 'at the time of the bombardment of the Danish fleet, an English sloop of war, riding at anchor in the roads at Copenhagen, blew up. In 1844, or thirty-seven years

* Jam. Ed. New Phil. Journ. No. xlviii. p. 435.

afterwards, one of our divers, known to be a trustworthy man, went down to save whatever might yet remain in the shipwrecked vessel. He found the space between decks entire, but covered with blocks from six to eight cubic feet in size, and some of them heaped one upon the other. He also affirmed, that all the sunk ships which he had visited in the Sound, were in like manner strewed over with blocks.'

Dr. Forchhammer also informs us, that during an intense frost in February 1844 the Sound was suddenly frozen over, and sheets of ice, driven by a storm, were heaped up at the bottom of the Bay of Täarbeijk, threatening to destroy a fishing-village on the shore. The whole was soon frozen together into one mass, and forced up on the beach, forming a mound more than 16 feet high, which threw down the walls of several buildings. 'When I visited the spot next day, I saw ridges of ice, sand, and pebbles, not only on the shore, but extending far out into the bottom of the sea, showing how greatly its bed had been changed, and how easily, where it is composed of rock, it may be furrowed and streaked by stones firmly fixed in the moving ice.' *

* Bulletin de la Soc. Géol. de France, 1847, tom. iv. pp. 1182, 1183.

CHAPTER XVII.

PHENOMENA OF SPRINGS.

ORIGIN OF SPRINGS—ARTESIAN WELLS—BORINGS AT PARIS—LIVE FISH RISING IN THE ARTESIAN WELLS IN THE SAHARA—DISTINCT CAUSES BY WHICH MINERAL AND THERMAL WATERS MAY BE RAISED TO THE SURFACE—THEIR CONNECTION WITH VOLCANIC AGENCY—THERMAL WATERS OF BATH—CALCAREOUS SPRINGS—TRAVERTIN OF THE ELSA—BATHS OF SAN VIGNONE AND OF SAN FILIPPO, NEAR RADICOFANI—SPHEROIDAL STRUCTURE IN TRAVERTIN—LAKE OF THE SOLFATARA, NEAR ROME—TRAVERTIN AT CASCADE OF TIVOLI—GYPSEOUS, SILICEOUS, AND FERRUGINOUS SPRINGS—BRINE SPRINGS—CARBONATED SPRINGS—DISINTEGRATION OF GRANITE IN AUVERGNE—PETROLEUM SPRINGS—PITCH LAKE OF TRINIDAD.

Origin of springs.—THE action of running water on the surface of the land having been considered, we may next turn our attention to what may be termed 'the subterranean drainage,' or the phenomena of springs. Everyone is familiar with the fact, that certain porous soils, such as loose sand and gravel, absorb water with rapidity, and that the ground composed of them soon dries up after heavy showers. If a well be sunk in such soils, we often penetrate to considerable depths before we meet with water; but this is usually found on our approaching some lower part of the porous formation where it rests on an impervious bed; for here the water, unable to make its way downwards in a direct line, accumulates as in a reservoir, and is ready to ooze out into any opening which may be made, in the same manner as we see the salt water filtrate into, and fill, any hollow which we dig in the sands of the shore at low tide.

The facility with which water can percolate loose and gravelly soils is clearly illustrated by the effect of the tides in the Thames between Richmond and London. The river, in this part of its course, flows through a bed of gravel overlying clay, and the porous superstratum is alternately saturated by the water of the Thames as the tide rises, and

then drained again to the distance of several hundred feet from the banks when the tide falls, so that the wells in this tract regularly ebb and flow.

The transmission of water through a porous medium being so rapid, we may easily understand why springs are thrown out on the side of a hill, where the upper set of strata consist of chalk, sand, or other permeable substances, while the subjacent are composed of clay or other retentive soils. The only difficulty, indeed, is to explain why the water does not ooze out everywhere along the line of junction of the two formations, so as to form one continuous land-soak, instead of a few springs only, and these oftentimes far distant from each other. The principal cause of such a concentration of the waters at a few points is, first, the existence of inequalities in the upper surface of the impermeable stratum, which lead the water, as valleys do on the external surface of a country, into certain low levels and channels, and secondly, the frequency of rents and fissures, which act as natural drains. That the generality of springs owe their supply to the atmosphere is evident from this, that they vary in the different seasons of the year, becoming languid or entirely ceasing to flow after long droughts, and being again replenished after a continuance of rain. Many of them are probably indebted for the constancy and uniformity of their volume to the great extent of the subterranean reservoirs with which they communicate, and the time required for these to empty themselves by percolation. Such a gradual and regulated discharge is exhibited, though in a less perfect degree, in all great lakes, for these are not sensibly affected in their levels by a sudden shower, but are only slightly raised, and their channels of efflux, instead of being swollen suddenly like the bed of a torrent, carry off the surplus water gradually.

Much light has been thrown, of late years, on the theory of springs, by the boring of what are called by the French 'Artesian wells,' because the method has long been known and practised in Artois: and it is now demonstrated that there are sheets, and in some places currents of fresh water,

at various depths in the earth. The instrument employed in excavating these wells is a large auger, and the cavity bored is usually from three to four inches in diameter. If a hard rock is met with, it is first triturated by an iron rod, and the materials, being thus reduced to small fragments or powder, are readily extracted. To hinder the sides of the well from falling in, as also to prevent the spreading of the ascending water in the surrounding soil, a jointed pipe is introduced, formed of wood in Artois, but in other countries more commonly of metal. It frequently happens that, after passing through hundreds of feet of retentive soils, a water-bearing stratum is at length pierced, when the fluid immediately ascends to the surface and flows over. The first rush of the water up the tube is often violent, so that for a time the water plays like a fountain, and then, sinking, continues to flow over tranquilly, or sometimes remains stationary at a certain depth below the orifice of the well. This spouting of the water in the first instance is owing to the disengagement of air and carbonic acid gas, both of which often bubble up with the water.*

At Sheerness, at the mouth of the Thames, a well was bored on a low tongue of land near the sea, through 300 feet of the blue clay of London, below which a bed of sand and pebbles was entered, belonging, doubtless, to the Woolwich beds: when this stratum was pierced, the water burst up with impetuosity, and filled the well. By another perforation at the same place, the water was found at the depth of 328 feet below the surface clay; it first rose rapidly 189 feet, and then, in the course of a few hours, ascended to an elevation of 8 feet above the level of the ground. In 1824 a well was dug at Fulham, near the Thames, at the Bishop of London's, to the depth of 317 feet, which, after traversing the Tertiary strata, was continued through 67 feet of chalk. The water immediately rose to the surface, and the discharge was about 50 gallons per minute. In the garden of the Horticultural Society at Chiswick, the borings passed through 19 feet of gravel, 242½ feet of clay and loam, and 67½ feet of chalk, and

* Consult J. Prestwich, Water-bearing Strata around London. 1851. (Van Voorst.)

the water then rose to the surface from a depth of 329 feet.* At the Duke of Northumberland's, above Chiswick, the borings were carried through a still greater thickness of incumbent strata down to the chalk, which was reached at the depth of 620 feet, when a considerable volume of water was obtained, which rose 4 feet above the surface of the ground. In a well of Mr. Brooks, at Hammersmith, the rush of water from a depth of 360 feet was so great as to inundate several buildings and do considerable damage; and at Tooting, a sufficient stream was obtained to turn a wheel, and raise the water to the upper stories of the houses.† In 1838, the total supply obtained from the chalk near London was estimated at six million gallons a day, and in 1851 at nearly double that amount, the increase being accompanied by an average fall of no less than two feet a year in the level to which the water rose. The water stood commonly, in 1822, at high-water mark, and had sunk in 1851 to 45, and in some wells to 65 feet below high-water mark.‡ This fact shows the limited capacity of the subterranean reservoir.

In the last of three wells bored through the chalk at Tours, to the depth of several hundred feet, the water rose 32 feet above the level of the soil, and the discharge amounted to 300 cubic yards of water every twenty-four hours.§ By way of a scientific experiment, the sinking of a well was commenced at Grenelle, in the suburbs of Paris, in 1834, which had reached, in November 1839, a depth of more than 1,600 English feet, and yet no water ascended to the surface. The government were persuaded by M. Arago to persevere, if necessary, to the depth of more than 2,000 feet; but when they had descended above 1,800 English feet below the surface, and reached the chloritic series (or upper greensand), the water rushed up through the boring, which was about 10 inches in diameter at its upper, and 6 at its lower extremity. The discharge every twenty-four hours was at the rate of half a million of gallons of limpid and warm water, the temperature being 82° F. This implies an

* Sabine, Journ. of Sci. No. xxxiii. p. 72, 1824.

† Héricart de Thury, 'Puits Forés,' p. 49.

‡ Prestwich, p. 69.

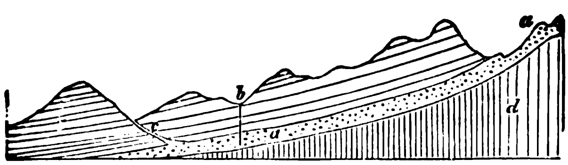
§ Bull. de la Soc. Géol. de France, tom. iii. p. 194

augmentation of 30° F. beyond the average of springs in the latitude of Paris, making a rate of increase of 1° F. for every 60 English feet of descent. The depth at which the successive strata, both tertiary and cretaceous, were encountered, agreed very closely with the anticipations of the scientific advisers of this most spirited undertaking.

Mr. Briggs, the British consul in Egypt, obtained water between Cairo and Suez, in a calcareous sand, at the depth of 30 feet; but it did not rise in the well.* But other borings in the same desert, of variable depth, between 50 and 300 feet, and which passed through alternations of sand, clay, and siliceous rock, yielded water at the surface.†

The rise and overflow of the water in Artesian wells is generally referred, and apparently with reason, to the same principle as the play of an artificial fountain. Let the porous stratum or set of strata, *a a*, rest on the impermeable rock *d*,

Fig. 33.



and be covered by another mass of an impermeable nature. The whole mass *a a* may easily, in such a position, become saturated with water, which may descend from its higher and exposed parts—a hilly region where rain falls abundantly. Suppose that at some point as at *b*, an opening be made, which gives a free passage upwards to the waters confined in *a a*, at so low a level, that they are subjected to the pressure of a considerable column of water collected in the more elevated portion of the same stratum. The water will then rush out, just as the liquid from a large barrel which is tapped, and it will rise to a height corresponding to the level of its point of departure, or, rather, to a height which balances the pressure previously exerted by

* Boué, Résumé des Prog. de la Géol. en 1832, p. 184.

† Seventh Rep. Brit. Assoc. 1837. p. 66.

the confined waters against the roof and sides of the stratum or reservoir *a a*. In like manner, if there happen to be a natural fissure *c*, a spring will be produced at the surface on precisely the same principle.

Among the causes of the failure of Artesian wells, we may mention those numerous rents and faults which abound in some rocks, and the deep ravines and valleys by which many countries are traversed; for, when these natural lines of drainage exist, there remains a small quantity only of water to escape by artificial issues. We are also liable to be baffled by the great thickness either of porous or impervious strata, or by the dip of the beds, which may carry off the waters from adjoining high lands to some trough in an opposite direction, as when the borings are made at the foot of an escarpment where the strata incline inwards, or in a direction opposite to the face of the cliffs.

The mere distance of hills or mountains need not discourage us from making trials: for the waters which fall on these higher lands readily penetrate to great depths through highly inclined or vertical strata, or through the fissures of shattered rocks, and after flowing for a great distance, must often re-ascend and be brought up again by other fissures, so as to approach the surface in the lower country. Here they may be concealed beneath a covering of undisturbed horizontal beds, which it may be necessary to pierce in order to reach them. It should be remembered, that the course of waters flowing under ground bears but a remote resemblance to that of rivers on the surface, there being, in the one case, a constant descent from a higher to a lower level from the source of the stream to the sea; whereas, in the other, the water may at one time sink far below the level of the ocean, and afterwards rise again high above it.

Among other curious facts ascertained by aid of the borer, it is proved that in strata of different ages and compositions, there are often open passages by which the subterranean waters circulate. Thus, at St. Ouen, in France, five distinct sheets of water were intersected in a well, and from each of these a supply obtained. In the third water-bearing stratum, at the depth of 150 feet, a cavity was found in which the

borer fell suddenly about a foot, and thence the water ascended in great volume.* A similar falling of the instrument several feet perpendicularly, as if in a hollow space, has been remarked in England and other countries. At Tours, in 1830, a well was perforated quite through the chalk, when the water suddenly brought up, from a depth of 364 feet, a great quantity of fine sand, with much vegetable matter and shells. Branches of a thorn several inches long, much blackened by their stay in the water, were recognised, as also the stems of marsh plants, and some of their roots, which were still white, together with the seeds of the same in a state of preservation, which showed that they had not remained more than three or four months in the water. Among the seeds were those of the marsh-plant *Galium uliginosum*; and among the shells, a fresh-water species, *Planorbis marginatus*, and some land species, as *Helix rotundata* and *H. striata*. M. Dujardin, who, with others, observed this phenomenon, supposes that the waters had flowed from some valleys of Auvergne or the Vivarais, distant about 150 miles, since the preceding autumn.†

An analogous phenomenon is recorded at Reimke, near Bochum in Westphalia, where the water of an Artesian well brought up, from a depth of 156 feet, several small fish, three or four inches long, the nearest streams in the country being at the distance of some leagues.‡ In some Artesian wells sunk by the French in the north-eastern part of the desert of the Sahara, small fish have been frequently brought up alive, with the first gush of water, from a depth of 175 feet. M. Désor informs us that in January 1863 he saw some of these fish in a well in the Oasis of Ain-Tala. They were of the genus Cyprinodon, not blind like those taken from the underground caverns of Adelsberg or Kentucky, but with perfect eyes.§ The nearest ponds or lakes were at a great distance on the surface of the desert, and in this and the other cases before mentioned of the subterranean transportation of shells, fish, and fragments of plants, we

* H. de Thury, p. 295.

† Bull. de la Soc. Géol. de France, tom. i. p. 93.

‡ Ibid. tom. ii. p. 248.

§ Gazette de Lausanne, Jan. 1864.

see evidence of the water not having been simply filtered through porous rock, but having flowed through continuous underground channels. Such examples suggest the idea that the leaky beds of rivers are often the feeders of springs.

MINERAL AND THERMAL SPRINGS.

Almost all springs, even those which we consider the purest, are impregnated with some foreign ingredients, which, being in a state of chemical solution, are so intimately blended with the water as not to affect its clearness, while they render it in general, more agreeable to our taste, and more nutritious than simple rain-water. But the springs called mineral contain an unusual abundance of earthy matter in solution, and the substances with which they are impregnated correspond remarkably with those evolved in a gaseous form by volcanos. Many of these springs are thermal, or have a higher temperature than that which belongs to ordinary springs in the same neighbourhood, and they rise up through all kinds of rock; as, for example, through granite, gneiss, limestone, or lava, but are most frequent in volcanic regions, or where violent earthquakes have occurred at eras comparatively modern.

The water given out by hot springs is generally more voluminous and less variable in quantity at different seasons than that proceeding from any others. In many volcanic regions, jets of steam, called by the Italians 'stufas,' issue from fissures, at a temperature high above the boiling point, as in the neighbourhood of Naples, and in the Lipari Isles, and are disengaged unceasingly for ages. Now, if such columns of steam, which are often mixed with other gases, should be condensed before reaching the surface by coming in contact with strata filled with cold water, they may give rise to thermal and mineral springs of every degree of temperature. It is, indeed, by such means rather than by hydrostatic pressure that in many cases we can best account for the rise of large bodies of water from great depths; nor can we hesitate to admit the adequacy of the cause, if we suppose the expansion of the same elastic fluids to be sufficient to raise columns of lava to the lofty summits of volcanic mountains. Several gases, carbonic acid in particular, are disengaged in a free

state from the soil of various districts, especially in regions of active or extinct volcanos; and the same are found more or less intimately combined with the waters of all mineral springs, both cold and thermal. Dr. Daubeny and other writers have remarked, not only that these springs are most abundant in volcanic regions, but that when remote from them, their site usually coincides with the position of some great derangement in the strata; a fault, for example, or great fissure, indicating that a channel of communication has been opened with the interior of the earth at some former period of local convulsion. It is also ascertained that at great heights in the Pyrenees and Himalaya Mountains, hot springs burst out from granitic rocks, and they are abundant in the Alps also, these chains having all been disturbed and dislocated at times comparatively modern, as can be shown by independent geological and sometimes historical evidence.

The small area of volcanic regions may appear, at first sight, to present an objection to these views, but not so when we include earthquakes among the effects of igneous agency. A large proportion of the land hitherto explored by geologists can be shown to have been rent or shaken by subterranean movements since the oldest Tertiary strata were formed. It will also be seen, in the sequel, that new springs have burst out, and others have had the volume of their waters augmented, and their temperature suddenly raised, after earthquakes, so that the description of these springs might almost with equal propriety have been given under the head of 'igneous causes,' as they are agents of a mixed nature, being at once igneous and aqueous.

As examples of changes which have occurred in historical times, I may here mention, that during the great earthquake at Lisbon in 1755, the temperature of the spring called La Source de la Reine, at Bagnères de Luchon in the Pyrenees, was suddenly raised as much as 75° F., or changed from a cold spring to one of 122° F., a heat which it has since retained. It is also recorded that the hot springs at Bagnères de Bigorre, in the same mountain-chain, became suddenly cold during a great earthquake which, in 1660, threw down several houses in that town.

But how, it will be asked, can the regions of volcanic heat send forth such inexhaustible supplies of water? The difficulty of solving this problem would, in truth, be insurmountable, if we believed that all the atmospheric waters found their way into the basin of the ocean; but in boring near the shore, we often meet with streams of fresh water at the depth of several hundred feet below the sea level; and most of these probably descend far beneath the bottom of the sea. Yet, how much greater may be the quantity of salt water which sinks beneath the floor of the ocean, through the porous strata of which it is often composed, or through fissures rent in it by earthquakes. After penetrating to a considerable depth, this water may encounter a heat of sufficient intensity to convert it into vapour, even under the high pressure to which it would then be subjected. This heat would probably be nearest the surface in volcanic countries, and farthest from it in those districts which have been longest free from eruptions or earthquakes.

In corroboration of such an opinion, I may mention, that in regions where volcanic eruptions still occur, hot springs are abundant, and occasionally attain a boiling temperature, while in proportion as we recede from such centres of igneous activity, the thermal waters decrease in frequency and average heat. In central France, or in the Eifel in Germany, we find cones and craters so perfect in their form, and streams of lava bearing such a relation to the shape of existing valleys, as to indicate that the internal fires have become dormant in comparatively recent times. It is precisely in these countries that hot springs play a conspicuous part.

It would follow from the views above explained, that there must be a twofold circulation of terrestrial waters; one caused by solar heat, and the other by heat generated in the interior of our planet. We know that the land would be unfit for vegetation if deprived of the waters raised into the atmosphere by the sun; but it is also true that mineral springs are powerful instruments in rendering the surface subservient to the support of animal and vegetable life. Their heat is believed to promote the development of the aquatic tribes in many parts of the ocean, and the substances which they carry

up from the bowels of the earth to the habitable surface, are of a nature and in a form which adapt them peculiarly for the nutrition of animals and plants.

As these springs derive their chief importance to the geologist from the quantity and quality of the earthy materials which, like volcanos, they convey from below upwards, they may properly be considered in reference to the ingredients which they hold in solution. These consist of a great variety of substances; but chiefly salts composed of carbonic, sulphuric, and hydrochloric acids combined with bases of lime, magnesia, alumina, and iron. Chloride of sodium, silica, and free carbonic acid, as well as nitrogen, are commonly present; there are also springs of petroleum or liquid bitumen, and of naphtha.

The ingredients of mineral springs, such as common salt, chloride of magnesium, and others, so often agree with the constituents of sea-water, that the theory of their marine origin has been naturally suggested. Such materials are, no doubt, often to be obtained from those strata through which the descending rain-water flows; but in many cases they may come from the sea even where the substances are not found in the same relative proportions as in sea-water; for where hot springs charged with gaseous matter penetrate through rocky masses, the decomposition of various minerals must often be going on, and where new chemical combinations take place, some of the gaseous, earthy, or metallic ingredients of springs may be intercepted in their upward course.

Among the gases, nitrogen is often largely evolved from springs, as it is from volcanic craters during eruptions. This gas may be derived, says Dr. Daubeny, from atmospheric air, which is always dissolved in rain-water, and which, when this water penetrates the earth's crust, must be carried down to great depths, so as to reach the heated interior. When there, it may be subjected to deoxidating processes, so that the nitrogen, being left in a free state, may be driven upwards by the expansive force of heat and steam, or by hydrostatic pressure.

Thermal waters of Bath.—The hot springs of Bath may

serve as an example of mineral waters containing in solution a variety of ingredients frequently met with in thermal springs. Their mean temperature is 120° Fahr., which is not only much above that of any other springs in England, but is exceptionally high in Europe, when we take into account their great distance from any region of active or extinct volcanos, or of violent earthquakes. Thus they are 400 miles distant from the Eifel volcanos, lying E.S.E. of them, and 440 miles from those (also extinct) of Auvergne, which lie to the S.E. The daily evolution of nitrogen gas amounts, according to Dr. Daubeny, to no less than 250 cubic feet in volume. This gas is largely disengaged from volcanic craters during eruptions, and carbonic acid gas is also evolved from the same springs. The other substances held in solution are the sulphates of lime and of soda, and the chlorides of sodium and magnesium. As the uniformity of temperature at all seasons of the year is remarkable in this, and in thermal springs generally, so is the uniformity of the discharge of water from century to century, and of the mineral ingredients held in solution. If we compare the hot water forced up by springs from below to the vast clouds of aqueous vapour evolved for days, or weeks in succession, from volcanic craters in eruption, so we may liken the voluminous masses of solid matter raised from great depths by the hot spring, to the lava which the volcano pours out on the surface. There is more analogy in the work done by the two agents, in raising up matter from great depths, than is commonly imagined. The waters of Bath are not conspicuous among European hot springs for the quantity of foreign matter which they contain, yet Professor Ramsay has calculated that, if the mineral ingredients which they pour out were solidified, they would form in one year a square column nine feet in diameter, and no less than 140 feet in height. All this matter is now quietly conveyed by a stream of limpid water, in an invisible form, to the Avon, and by the Avon to the sea; but if, instead of being thus removed, it were deposited round the orifice of eruption, like the siliceous layers which encrust the circular basin of an Icelandic geyser, we should soon see a considerable cone built up, with a crater in the

middle; and if the action of the spring were intermittent, so that ten or twenty years should elapse between the periods when solid matter was emitted, or (say) an interval of three centuries, as in the case of Vesuvius between 1306 and 1631, the discharge would be on so grand a scale as to afford no mean object of comparison with the intermittent outpourings of a volcano.*

Calcareous springs.—Springs which are highly charged with calcareous matter produce a variety of phenomena of much interest in geology. It is known that rain-water collecting carbonic acid from the atmosphere has the property of dissolving the calcareous rocks over which it flows, and thus, in the smallest ponds and rivulets, matter is often supplied for the earthy secretions of testacea, and for the growth of certain plants on which they feed. But many springs hold so much carbonic acid in solution, that they are enabled to dissolve a much larger quantity of calcareous matter than rain-water: and when the acid is dissipated in the atmosphere, the mineral ingredients are thrown down, in the form of porous tufa or of more compact travertin.

Auvergne.—Calcareous springs, although most abundant in limestone districts, are by no means confined to them, but flow out indiscriminately from all rock formations. In Central France, a district where the primary rocks are unusually destitute of limestone, springs copiously charged with carbonate of lime rise up through the granite and gneiss. Some of these are thermal, and probably derive their origin from the deep source of volcanic heat, once so active in that region. One of these springs, at the northern base of the hill upon which Clermont is built, issues from volcanic peperino, which rests on granite. It has formed, by its incrustations, an elevated mound of travertin, or white concretionary limestone, 240 feet in length, and at its termination, sixteen feet high and twelve wide. Another encrusting spring in the same department, situated at Chaluzet, near Pont Gibaud, rises in a gneiss country, at the foot of a regular volcanic cone, at least twenty miles from any calcareous rock.

* Lyell. Anniversary Address, British Association, 1864.

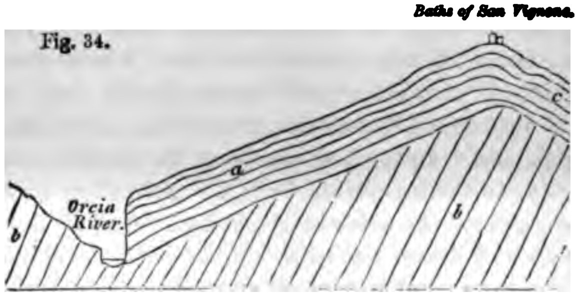
Some masses of tufaceous deposit, produced by this spring, have an oolitic texture.

Valley of the Elsa.—If we pass from the volcanic district of France to that which skirts the Apennines in the Italian peninsula, we meet with innumerable springs which have precipitated so much calcareous matter, that the whole ground in some parts of Tuscany is coated over with tufa and travertin, and sounds hollow beneath the foot.

In other places in the same country, compact rocks are seen descending the slanting sides of hills, very much in the manner of lava currents, except that they are of a white colour and terminate abruptly when they reach the course of a river. These consist of a calcareous precipitate from springs, some of which are still flowing, while others have disappeared or changed their position. Such masses are frequent on the slope of the hills which bound the valley of the Elsa, one of the tributaries of the Arno, which flows near Colle, through a valley several hundred feet deep, shaped out of a lacustrine formation, containing fossil shells of existing species. I observed here that the travertin was unconformable to the lacustrine beds, its inclination according with the slope of the sides of the valley. One of the finest examples which I saw was at the Molino delle Caldane, near Colle. The Sena, and several other small rivulets which feed the Elsa, have the property of encrusting wood and herbs with calcareous stone. In the bed of the Elsa itself, aquatic plants, such as Charæ, which absorb large quantities of carbonate of lime, are very abundant.

Baths of San Vignone.—Those persons who have merely seen the action of petrifying waters in England, will not easily form an adequate conception of the scale on which the same process is exhibited in those regions which lie nearer to the active centres of volcanic disturbance. One of the most striking examples of the rapid precipitation of carbonate of lime from thermal waters, occurs in the hill of San Vignone in Tuscany, at a short distance from Radicofani, and only a few hundred yards from the high road between Sienna and Rome. The spring issues from near the summit of a rocky hill, about 100 feet in height. The top of the hill stretches

in a gently inclined platform to the foot of Mount Amiata, a lofty eminence, which consists in great part of volcanic products. The fundamental rock, from which the spring issues, is a black slate, with serpentine (*b b*, fig. 34), belonging to the older Apennine formation. The water is hot, has a strong taste, and, when not in very small quantity, is of a bright green colour. So rapid is the deposition near the source, that in the bottom of a conduit pipe for carrying off the water to the baths, and which is inclined at an angle of 30°, half a foot of solid travertin is formed every year. A more compact rock is produced where the water flows slowly; and the precipitation in winter, when there is least evaporation, is said to be more solid, but less in quantity by one fourth, than in summer. The rock is generally white; some



Section of travertin, San Vignone.

parts of it are compact, and ring to the hammer; others are cellular, and with such cavities as are seen in the carious part of bone or the siliceous millstone of the Paris basin. A portion of it also below the village of San Vignone consists of incrustations of long vegetable tubes, and may be called tufa. Sometimes the travertin assumes precisely the botryoidal and mammillary forms, common to similar deposits in Auvergne, of a much older date; and, like them, it often scales off in thin, slightly undulating layers.

A large mass of travertin (*c*, fig. 34) descends the hill from the point where the spring issues, and reaches to the distance of about half a mile east of San Vignone. The beds take the slope of the hill at about an angle of 6°, and the planes of stratification are perfectly parallel. One stratum, com

posed of many layers, is of a compact nature, and fifteen feet thick; it serves as an excellent building stone, and a mass of fifteen feet in length was, in 1828, cut out for the new bridge over the Orcia. Another branch of it (*a*, fig. 34) descends to the west, for a length of 250 feet, varying in thickness, but sometimes more than 20 feet deep: it is then cut off by the small river Orcia, as some glaciers in Switzerland descend into a valley till their progress is suddenly arrested by a transverse stream of water.

The abrupt termination of the mass of rock, at the river where its thickness is undiminished, clearly shows that it would proceed much farther if not arrested by the stream, over which it impends slightly. But it cannot encroach upon the channel of the Orcia, being constantly undermined, so that its solid fragments are seen strewed amongst the alluvial gravel. However enormous, therefore, the mass of solid rock may appear which has been given out by this single spring, we may feel assured that it is insignificant in volume when compared to that which has been carried to the sea since the time it began to flow. What may have been the length of that period of time we have no data for conjecturing. In quarrying the travertin, Roman tiles have been sometimes found at the depth of five or six feet.

Baths of San Filippo.—On another hill, not many miles from that last mentioned, and also connected with Mount Amiata, the summit of which is about three miles distant, are the celebrated baths of San Filippo. The subjacent rocks consist of alternations of black slate, limestone, and serpentine. There are three warm springs containing carbonate and sulphate of lime, and sulphate of magnesia. The water which supplies the baths falls into a pond, where it has been known to deposit a solid mass *thirty feet thick* in about *twenty years.** A manufactory of medallions in basso-relievo is carried on at these baths. The water is conducted by canals into several pits, in which it deposits travertin and crystals of sulphate of lime. After being thus freed from its grosser parts, it is conveyed by a tube to the summit of a small chamber, and made to fall through a space of ten or

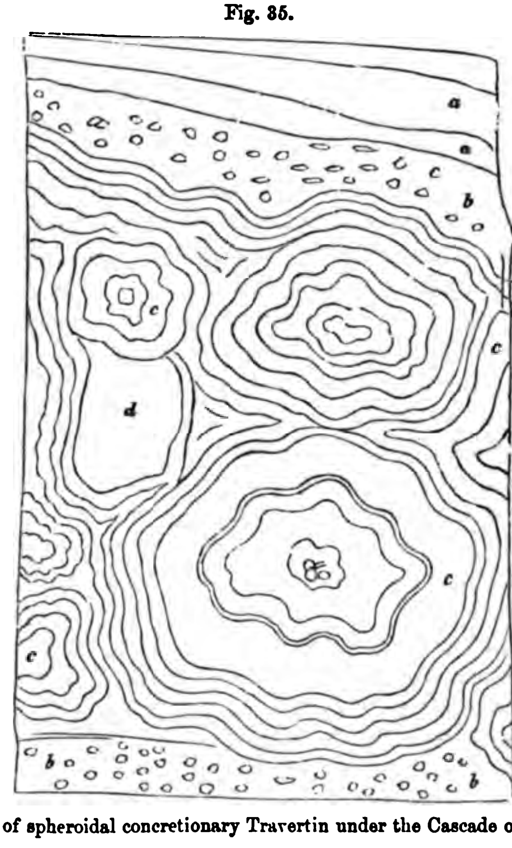
* Dr. Grosse on the Baths of San Filippo, Ed. Phil. Journ. vol. ii. p. 292.

twelve feet. The current is broken in its descent by numerous crossed sticks, by which the spray is dispersed around upon certain moulds, which are rubbed lightly over with a solution of soap, and a deposition of solid matter like marble is the result, yielding a beautiful cast of the figures formed in the mould. The geologist may derive from these experiments considerable light, in regard to the high slope of the strata at which some semi-crystalline precipitations can be formed; for some of the moulds are disposed almost perpendicularly, yet the deposition is nearly equal in all parts.

Spheroidal structure in travertin.—Travertin of Tivoli.—But what renders this recent limestone of peculiar interest to the geologist, is the spheroidal form which it assumes, analogous to that of the cascade of Tivoli (see fig. 35), in the neighbourhood of Rome. Here the calcareous waters of the Anio incrust the reeds which grow on its banks, and the foam of the cataract of Tivoli forms beautiful pendent stalactites. On the sides of the deep chasm into which the cascade throws itself there is seen an extraordinary accumulation of horizontal beds of tufa and travertin, from four to five hundred feet in thickness. The section immediately under the temples of Vesta and the Sibyl displays, in a precipice about four hundred feet high, some spheroids which are from *six to eight feet in diameter*, each concentric layer being about the eighth of an inch in thickness. The following diagram exhibits about fourteen feet of this immense mass, as seen in the path cut out of the rock in descending from the temple of Vesta to the Grotto di Nettuno. I have not attempted to express in this drawing the innumerable thin layers of which these magnificent spheroids are composed, but the lines given mark some of the natural divisions into which they are separated by minute variations in the size or colour of the laminæ. The undulations also are much smaller in proportion to the whole circumference than in the drawing. The beds (*a a*) are of hard travertin and soft tufa; below them is a pisolite (*b*), the globules being of different sizes: underneath this appears a mass of concretionary travertin (*c c*), some of the spheroids being of the above-mentioned extraordinary size. In some

places (as at *d*) there is a mass of amorphous limestone, or tufa, surrounded by concentric layers. At the bottom is another bed of pisolite (*b*), in which the small nodules are about the size and shape of beans, and some of them of filberts, intermixed with some smaller oolitic grains. In the tufaceous strata, wood is seen converted into a light tufa.

Fig. 35.



Section of spheroidal concretionary Travertin under the Cascade of Tivoli.

The lamination of some of the concentric masses is so minute that sixty may be counted in the thickness of an inch; yet, notwithstanding these marks of gradual and successive deposition, sections are sometimes exhibited of what might seem to be perfect spheres. This tendency to a mammillary and globular structure arises from the facility with which

the calcareous matter is precipitated in nearly equal quantities on all sides of any fragment of shell or wood, or any inequality of the surface over which the mineral water flows, the form of the nucleus being readily transmitted through any number of successive envelopes. But these masses can never be perfect spheres, although they often appear such when a transverse section is made in any line not in the direction of the point of attachment. There are, indeed, occasionally seen small oolitic and pisolitic grains, of which the form is globular: for the nucleus, having been for a time in motion in the water, has received fresh accessions of matter on all sides.

In the same manner I have seen, on the vertical walls of large steam-boilers, the heads of nails or rivets covered by a series of enveloping crusts of calcareous matter, usually sulphate of lime; so that a concretionary nodule is formed, preserving a nearly globular shape, when increased to a mass several inches in diameter. In these, as in many travertins, there is often a combination of the concentric and radiated structure.

There can be little doubt that the whole of this deposit was formed in an extensive lake which existed at the close of the period of volcanic activity by which the lavas and tuffs of the Roman territory were formed. The external configuration of the country has since been greatly changed, and the Anio now throws itself into a ravine excavated in the ancient travertin. Its waters give rise to masses of calcareous stone, scarcely if at all distinguishable from the older rock. I was shown, in 1828, in the upper part of the travertin, the hollow left by a cart-wheel, in which the outer circle and the spokes had been decomposed, and the spaces which they filled left void. It seemed to me at the time impossible to explain the position of this mould, without supposing that the wheel was imbedded before the lake was drained; but Sir R. Murchison suggests that it may have been washed down by a flood into the gorge in modern times, and then incrusted with calcareous tufa in the same manner as the wooden beam of the church of St. Lucia was swept down in 1826, and stuck fast in the Grotto of the Syren,

where it still remains, and will eventually be quite imbedded in travertin.*

Campagna di Roma.--The country around Rome, like many parts of the Tuscan States already referred to, has been at some former period the site of numerous volcanic eruptions; and the springs are still copiously impregnated with lime, carbonic acid, and sulphuretted hydrogen. A hot spring was discovered about 1827, near Civita Vecchia, by Signor Riccioli, which deposits alternate beds of a yellowish travertin, and a white granular rock, not distinguishable, in hand specimens, either in grain, colour, or composition, from statuary marble. There is a passage between this and ordinary travertin. The mass accumulated near the spring is in some places about six feet thick.

Lake of the Solfatara.—In the Campagna, between Rome and Tivoli, is the Lake of the Solfatara, called also Lago di Zolfo (lacus albula), into which flows continually a stream of tepid water from a smaller lake, situated a few yards above it. The water is a saturated solution of carbonic acid gas, which escapes from it in such quantities in some parts of its surface, that it has the appearance of being actually in ebullition. 'I have found by experiment,' says Sir Humphry Davy, 'that the water taken from the most tranquil part of the lake, even after being agitated and exposed to the air, contained in solution more than its own volume of carbonic acid gas, with a very small quantity of sulphuretted hydrogen. Its high temperature, which is pretty constant at 80° of Fahr., and the quantity of carbonic acid that it contains, render it peculiarly fitted to afford nourishment to vegetable life. The banks of travertin are everywhere covered with reeds, lichen, confervæ, and various kinds of aquatic vegetables; and at the same time that the process of vegetable life is going on, the crystallisations of the calcareous matter, which is everywhere deposited, in consequence of the escape of carbonic acid, likewise proceed.—There is, I believe, no place in the world where there is a more striking example of the opposition or contrast of the laws of animate and inanimate nature, of the

* Murchison, Geol. Quart. Journ., 1850, vol. vi. p. 293.

forces of inorganic chemical affinity, and those of the powers of life.' *

The same observer informs us that he fixed a stick in a mass of travertin covered by the water in the month of May, and in April following he had some difficulty in breaking, with a sharp-pointed hammer, the mass which adhered to the stick, and which was several inches in thickness. The upper part was a mixture of light tufa and the leaves of confervæ; below this was a darker and more solid travertin, containing black and decomposed masses of confervæ; in the inferior part the travertin was more solid, and of a grey colour, but with cavities probably produced by the decomposition of vegetable matter.†

The stream which flows out of this lake fills a canal about nine feet broad and four deep, and is conspicuous in the landscape by a line of vapour which rises from it. It deposits calcareous tufa in this channel, and the Tiber probably receives from it, as well as from numerous other streams, much carbonate of lime in solution, which may contribute to the rapid growth of its delta. A large proportion of the most splendid edifices of ancient and modern Rome are built of travertin, derived from the quarries of Ponte Lucano, where there has evidently been a lake at a remote period, on the same plain as that already described.

Sulphureous and gypseous springs.—The quantity of other mineral ingredients wherewith springs in general are impregnated is insignificant in comparison to lime, and this earth is most frequently combined with carbonic acid. But, as sulphuric acid and sulphuretted hydrogen are very frequently supplied by springs, gypsum may, perhaps, be deposited largely in certain seas and lakes. Among other gypseous precipitates at present known on the land, I may mention those of Baden, near Vienna, from the springs which feed the public bath. Some of these supply singly from 600 to 1,000 cubic feet of water per hour, and deposit a fine powder, composed of a mixture of sulphate of lime with sulphur and muriate of lime.‡ The thermal waters of Aix,

* Consolations of Travel, pp. 123–125.

† Ibid. p. 127.

‡ C. Prevost, Essai sur la Constitution physique du Bassin de Vienne, p. 10.

in Savoy, in passing through strata of Jurassic limestone, turn them into gypsum or sulphate of lime. In the Andes, at the Puenta del Inca, Lieutenant Brand found a thermal spring at the temperature of 91° Fahr., containing a large proportion of gypsum with carbonate of lime and other ingredients.* Many of the mineral springs of Iceland, says Professor Bunsen, deposit gypsum,† and sulphureous acid gas escapes plentifully from them as from the volcanos of the same island. It may, indeed, be laid down as a general rule, that the mineral subtances, as before stated, dissolved in hot springs agree very closely with those which are disengaged in a gaseous form from the craters of active volcanos.

Siliceous springs.—Azores.—In order that water should hold a very large quantity of silica in solution, it seems necessary that it should be raised to a high temperature.‡ The hot springs of the Valle das Fernas, in the island of St. Michael, rising through volcanic rocks, precipitate vast quantities of siliceous sinter. Around the circular basin of the largest spring, which is between twenty and thirty feet in diameter, alternate layers are seen of a coarser variety of sinter mixed with clay, including grass, ferns, and reeds, in different states of petrifaction. In some instances, alumina, which is likewise deposited from the hot waters, is the mineralising material. Branches of the same ferns which now flourish in the island are found completely petrified, preserving the same appearance as when vegetating, except that they acquire an ash-grey colour. Fragments of wood, and an entire stratum from three to five feet thick, composed of reeds now common in the island, have become completely mineralised.

The most abundant variety of siliceous sinter occurs in layers, from a quarter to half an inch in thickness, accumulated on each other often to the height of a foot and upwards, and constituting parallel, and for the most part horizontal, strata many yards in extent. This sinter has often a beautiful semi-opalescent lustre. A recent breccia is also in the

* Travels across the Andes, p. 240.

† Annalen der Chem. 1847.

‡ Daubeny on Volcanos, p. 222.

act of forming, composed of obsidian, pumice, and scoriæ, cemented by siliceous sinter.*

Geysers of Iceland.—The origin of the Icelandic Geysers, or the cause of the intermittent play of those thermal fountains, will be fully considered in Chap. XXXIII. when volcanic action is treated of. I shall merely allude to them here as illustrating the deposition of silex now in progress.† The circular reservoirs into which the geysers fall, are lined in the interior with a variety of opal, and round the edges with sinter. The plants incrusted with the latter substance have much the same appearance as those incrusted with calcareous tufa in our own country. They consist of various grasses, the horse-tail (*Equisetum*), and leaves of the birch-tree, which are the most common of all, though no trees of this species now exist in the surrounding country. The petrified stems also of the birch occur in a state much resembling agatised wood.‡

By analysis of the water, Faraday ascertained that the solution of the silex is promoted by the presence of the alkali, soda. He suggested that the deposition of silica in an insoluble state takes place partly because the water when cooled by exposure to the air is unable to retain as much silica as when it issues from the earth at a temperature of 180° or 190° Fahr., and partly because the evaporation of the water decomposes the compound of silica and soda which previously existed. This last change is probably hastened by the carbonic acid of the atmosphere uniting with the soda. The alkali, when disunited from the silica, would readily be dissolved in and removed by running water.§

Mineral waters, even when charged with a small proportion of silica, as those of Ischia, may supply certain species of corals, sponges, and infusoria with matter for their siliceous secretions; but there is little doubt that rivers obtain silex in solution from another and far more general source, namely, the decomposition of felspar. When this mineral,

* Dr. Webster on the Hot Springs of Furnas, Ed. Phil. Journ. vol. vi. p. 306.

† See a cut of the Icelandic geyser, Chap. XXXIII.

‡ M. Robert, Bulletin de la Soc. Géol. de France, tom. vii. p. 11.

§ Barrow's Iceland, p. 209.

which is so abundant an ingredient in the hypogene and trappean rocks, has disintegrated, it is found that the residue, called porcelain clay, contains but a small proportion of the silica which existed in the original felspar, the other part having been dissolved and removed by water.*

Ferruginous springs.—The waters of almost all springs contain some iron in solution; and it is a fact familiar to all, that many of them are so copiously impregnated with this metal, as to stain the rocks or herbage through which they pass, and to bind together sand and gravel into solid masses. We may naturally, then, conclude that this iron, which is constantly conveyed from the interior of the earth into lakes and seas, and which does not escape again from them into the atmosphere by evaporation, must act as a colouring and cementing principle in the subaqueous deposits now in progress. Geologists are aware that many ancient sandstones and conglomerates are bound together or coloured by iron.

Brine springs.—So great is the quantity of chloride of sodium in some springs, that they yield one fourth of their weight in salt. They are rarely, however, so saturated, and generally contain, intermixed with salt, carbonate and sulphate of lime, magnesia, and other mineral ingredients. The brine springs of Cheshire are the richest in our country; those of Northwich being almost saturated. There are others also in Lancashire and Worcestershire which are extremely rich.† They are known to have flowed for more than 1,000 years, and the quantity of salt which they have carried into the Severn and Mersey must be enormous. These brine springs rise up through strata of sandstone and red marl, which contain large beds of rock salt. The origin of the brine, therefore, may be derived in this and many other instances from beds of fossil salt; but as chloride of sodium is one of the products of volcanic emanations and of springs in volcanic regions, the original source of salt may be as deep-seated as that of lava.

Many springs in Sicily contain muriate of soda, and the

* See Lyell's Elements of Geology; and Dr. Turner, Jam. Ed. New Phil. Journ. No. xxx. p. 246.

† L. Horner, Geol. Trans. vol. iii. p. 94.

'fiume salso,' in particular, is impregnated with so large a quantity that cattle refuse to drink of it. A hot spring rising through granite, at Saint Nectaire, in Auvergne, may be mentioned as one of many, containing a large proportion of salt, together with magnesia and other ingredients.*

Carbonated springs.—Auvergne.—Carbonic acid gas is very plentifully disengaged from springs in almost all countries, but particularly near active or extinct volcanos. It has the property of decomposing many of the hardest rocks with which it comes in contact, particularly that numerous class in whose composition felspar is an ingredient. It renders the oxide of iron soluble in water, and contributes, as was before stated, to the solution of calcareous matter. In volcanic districts these gaseous emanations are not confined to springs, but rise up in the state of pure gas from the soil in various places. The Grotto del Cane, near Naples, affords an example, and prodigious quantities are now annually disengaged from every part of the Limagne d'Auvergne, where it appears to have been plentifully evolved from time immemorial. As the acid is invisible, it is not observed, except an excavation be made, wherein it often accumulates, so that it will extinguish a candle. There are some springs in this district where the water is seen bubbling and boiling up with much noise, in consequence of the abundant disengagement of this gas. In the environs of Pont-Gibaud, not far from Clermont, a rock belonging to the gneiss formation, in which lead-mines are worked, has been found to be quite saturated with carbonic acid gas, which is constantly disengaged. The carbonates of iron, lime, and manganese are so dissolved, that the rock is rendered soft, and the quartz alone remains unattacked.† Not far off is the small volcanic cone of Chaluzet, which once broke up through the gneiss, and sent forth a lava-stream.

Disengagement of free carbonic acid.—Prof. Bischoff, in his history of volcanos,‡ has shown what enormous quantities of

* Ann. de l'Auvergne, tome i. p. 234.

† Ann. scient. de l'Auvergne, tome ii. June 1829.

‡ Edinb New Phil. Journ. Oct. 1839.

carbonic acid gas are exhaled in the vicinity of the extinct craters of the Rhine (in the neighbourhood of the Laacher-see, for example, and the Eifel), and also in the mineral springs of Nassau and other countries, where there are no such traces of modern volcanic action. It would be easy to calculate in how short a period the solid carbon, thus emitted from the interior of the earth in an invisible form, would amount to a quantity as great as could be obtained from the trees of a large forest, and how many thousand years would be required to supply the materials of a dense seam of pure coal from the same source. I have already alluded (p. 226) to the doctrine favoured by some geologists of the existence of an atmosphere highly charged with carbonic acid, at the period of the ancient coal-plants, and have endeavoured to show that the opinion is untenable.* We have no right to draw such an inference as to the former chemical constitution of the atmosphere, until we have data for estimating the volume of carbonic acid gas emitted from the earth in volcanic regions, or given out by dead animal and vegetable substances during putrefaction, and comparing it with the volume of the same gas annually extracted from the air, and afterwards stored up in the earth's crust in the form of peat, buried timber, and organic matter derived from the animal kingdom.

Disintegrating effects of carbonic acid.—The disintegration of granite is a striking feature of large districts in Auvergne, especially in the neighbourhood of Clermont. This decay was called by Dolomieu 'la maladie du granite.' The phenomenon may, without doubt, be ascribed to the continual disengagement of carbonic acid gas from numerous fissures.

In the plains of the Po, between Verona and Parma, especially at Villa Franca, south of Mantua, I observed great beds of alluvium, consisting chiefly of pebbles of crystalline rock, percolated by spring-water, charged with carbonate of lime and carbonic acid in great abundance. They are for the most part incrusted with calc-sinter; and the rounded blocks of gneiss, which have all the outward appearance of

* See Lyell's Travels in N. America. June 1829.

solidity, and which could only have acquired their shape by trituration when extremely hard, have been so disintegrated by the carbonic acid as readily to fall to pieces.

The subtraction of many of the elements of rocks by the solvent power of carbonic acid, ascending both in a gaseous state and mixed with spring-water in the crevices of rocks, must be one of the most active sources of those internal changes and re-arrangements of particles so often observed in strata of every age. The calcareous matter, for example, of shells, is often entirely removed and replaced by carbonate of iron, pyrites, silex, or some other ingredient, such as mineral waters usually contain in solution. It rarely happens, except in limestone rocks, that the carbonic acid can dissolve all the constituent parts of the mass; and for this reason, probably, calcareous rocks are almost the only ones in which great caverns and long winding passages are found.

Petroleum springs.—Springs of which the waters contain a mixture of petroleum, or rock oil, which is a compound of hydrogen and carbon, and the various minerals allied to it, such as naphtha and asphalt or mineral pitch, are very numerous. All these substances, says Mr. T. Sterry Hunt, are forms of bitumen, some, like petroleum, being fluid, others, like asphalt, being solid at ordinary temperatures. They are supposed to be all of organic origin, derived partly from terrestrial, partly from marine plants, and sometimes from animal remains; for portions, says Mr. Hunt, of the tissues of various marine animals of low grade are destitute of nitrogen, and very similar in mineral composition to the woody fibre of plants. The probability, in some cases, of an animal origin has been especially inferred from the frequency of what is called anthracite in the 'calciferous beds' of the Lower Silurian of New York. The anthracite of this ancient rock, says Mr. Hunt, is an inspissated mineral oil. Petroleum is found in formations of every age, from the Lower Silurian up to the Tertiary; but a large number of the oil-wells of the United States, which have lately attracted so much attention, are in Carboniferous and Devonian rocks.

In some instances the petroleum appears to filter slowly into the wells from the porous strata around, which are satu-

rated with it it, while at other times the boring instrument seems to strike upon a fissure communicating with a reservoir which furnishes at once great volumes of oil.*

The great pitch lake of Trinidad is situated, according to Mr. Wall, in Tertiary strata, chiefly Upper Miocene, but partly, perhaps, Lower Pliocene. The asphalt is derived from bituminous shales, containing vegetable remains, which are sometimes seen in the process of transformation, with their organic structure more or less obliterated. Occasionally the bituminous substance becomes plastic and even oily, and rises to the surface.† Such changes from oil to a pitch may be brought about, says Mr. T. S. Hunt, partly by the evaporation of the volatile ingredients, and partly by oxidation from the air.

Captain Mallet observes that, near Cape La Braye, in the island of Trinidad, fluid bitumen sometimes oozes out from the bottom of the sea, and rises to the surface. The same author quotes Gumilla, as stating, in his 'Description of the Orinoco,' that 'about seventy years ago, a spot of land on the western coast of Trinidad, near half-way between the capital and an Indian village, sank suddenly, and was immediately replaced by a small lake of pitch, to the great terror of the inhabitants.'‡

A similar subsidence, at an earlier period, may probably have given rise to the great pitch lake of Trinidad, the cavity having become gradually filled with asphalt. Every geologist is familiar with the odour emitted from what are called fetid limestones when first broken. The Niagara limestone of the Upper Silurian group in America is sometimes so impregnated with bitumen, that this substance, when the stone is burned for lime, flows from the kiln like tar.§

* Sterry Hunt, Canadian Naturalist, vol. vi. p. 245. August 1861.

† Wall. Quart. Geol. Journ. vol. xvi. p. 468. 1860.

‡ Mallet, cited by Dr. Nugent, Geol. Trans. vol. i. p. 69. 1811.

§ T. S. Hunt, ibid. p. 245.

CHAPTER XVIII.

REPRODUCTIVE EFFECTS OF RIVERS.

LAKE DELTAS—GROWTH OF THE DELTA OF THE UPPER RHONE IN THE LAKE OF GENEVA—PLAYFAIR ON THE ORIGIN OF LAKE-BASINS—COMPUTATION OF THE AGE OF DELTAS—RECENT DEPOSITS IN LAKE SUPERIOR—DELTAS OF INLAND SEAS—COURSE OF THE PO—ARTIFICIAL EMBANKMENTS OF THE PO AND ADIGE—DELTA OF THE PO, AND OTHER RIVERS ENTERING THE ADRIATIC—RAPID CONVERSION OF THE GULF INTO LAND—MINERAL CHARACTERS OF THE NEW DEPOSITS—MARINE DELTA OF THE RHONE—VARIOUS PROOFS OF ITS INCREASE—STONY NATURE OF ITS DEPOSITS—COAST OF ASIA MINOR—DELTA OF THE NILE—CHRONOLOGICAL COMPUTATION OF THE GROWTH OF THE NILE MUD AT MEMPHIS.

DELTAS IN LAKES.

I HAVE already spoken, in the fourteenth chapter, of the action of running water, and of the denuding power of rivers, but we can only form a just conception of the excavating and removing force exerted by such bodies of water, when we have the advantage of examining the reproductive effects of the same agents: in other words, of beholding in a palpable form the aggregate amount of matter which they have thrown down at certain points in their alluvial plains, or in the basins of lakes and seas. Yet it will appear when we consider the action of currents, that the growth of deltas affords a very inadequate standard by which to measure the entire carrying power of running water, since a considerable portion of fluviatile sediment is swept far out to sea.

Deltas may be divided into, first, those which are formed in lakes; secondly, those in inland seas, where the tides are almost imperceptible; and, thirdly, those on the borders of the ocean. The most characteristic distinction between the lacustrine and marine deltas consists in the nature of the organic remains which become imbedded in their deposits;

for, in the case of a lake, it is obvious that these must consist exclusively of such genera of animals as inhabit the land or the waters of a river or lake; whereas, in the other case, there will be an admixture, and most frequently a predominance, of animals which inhabit salt water. In regard, however, to the distribution of inorganic matter, the deposits of lakes and seas are formed under very analogous circumstances.

Lake of Geneva.—Lakes exemplify the first reproductive operations in which rivers are engaged when they convey the detritus of rocks and the ingredients of mineral springs from higher to lower regions. The accession of new land at the mouth of the Rhone, at the upper end of the Lake of Geneva, or the Leman Lake, presents us with an example of a considerable thickness of strata which have accumulated since the historical era. This sheet of water is about 1,200 feet above the sea, thirty-seven miles long, and its breadth is from two to eight miles. The shape of the bottom is very irregular, the depth having been found to vary from 20 to 160 fathoms.* The Rhone, where it enters at the upper end, is turbid and discoloured; but its waters, where it issues at the town of Geneva, are beautifully clear and transparent. An ancient town, called Port Vallais (Portus Valesiæ of the Romans), once situated at the water's edge, at the upper end, is now more than a mile and a half inland—this intervening alluvial tract having been acquired in about eight centuries. The remainder of the delta consists of a flat alluvial plain, about five or six miles in length, composed of sand and mud, a little raised above the level of the river, and full of marshes.

Sir Henry De la Beche found, after numerous soundings in all parts of the lake, that there was a pretty uniform depth of from 120 to 160 fathoms throughout the central region, and on approaching the delta the shallowing of the bottom began to be very sensible at a distance of about a mile and three-quarters from the mouth of the Rhone; for a line drawn from St. Gingoulph to Vevey gives a mean depth of somewhat less than 600 feet, and from that part to the

* De la Beche, Ed. Phil. Journ. vol. ii. p. 107. Jan. 1820.

Rhone, the fluviatile mud is always found along the bottom.* We may state, therefore, that the new strata annually produced are thrown down upon a slope about two miles in length; so that, notwithstanding the great depth of the lake, the new deposits are inclined at so slight an angle, that they would be termed, in ordinary geological language, horizontal.

The strata probably consist of alternations of finer and coarser particles; for, during the hotter months from April to August, when the snows melt, the volume and velocity of the river are greatest, and large quantities of sand, mud, vegetable matter, and drift-wood are introduced; but during the rest of the year the influx is comparatively feeble, so much so, that the whole lake, according to Saussure, stands six feet lower. If, then, we could obtain a section of the accumulation formed in the last eight centuries, we should see a great series of strata, probably from 600 to 900 feet thick, and nearly two miles in length, inclined at a very slight angle. A much more considerable deposit of similarly stratified matter, of an age antecedent to the historical, would be seen extending to the original head of the lake five or six miles distant from the accumulations of the last 800 years. Simultaneously with the growth of the principal delta, a great number of rapid torrents are bringing down large masses of sand and pebbles, and forming smaller deltas at their mouths round the borders of the lake. The body of water in such torrents is too small to enable them to spread out the transported matter over so extensive an area as the Rhone does. Thus, for example, there is a depth of eighty fathoms within half a mile of the shore, immediately opposite the great torrent which enters east of Ripaille, so that the dip of the strata in that minor delta must be about four times as great as that of the deposits formed by the main river at the upper extremity of the lake.†

The capacity of this basin being now ascertained, it would be an interesting subject of enquiry, to determine in what number of years the Leman Lake will be converted into dry land. It would not be very difficult to obtain the elements

* De la Beche, MS. † Ibid.

for such a calculation, so as to approximate at least to the quantity of time required for the accomplishment of the result. The number of cubic feet of water annually discharged by the river into the lake being estimated, experiments might be made in the winter and summer months, to determine the proportion of matter held in suspension or in chemical solution by the Rhone. It would be also necessary to allow for the heavier matter drifted along at the bottom, which might be estimated on hydrostatic principles, when the average size of the gravel and the volume and velocity of the stream at different seasons were known. Supposing all these observations to have been made, it would be more easy to calculate the future than the former progress of the delta, because it would be a laborious task to ascertain, with any degree of precision, the original depth and extent of that part of the lake which is already filled up. Even if this information were actually obtained by borings, it would only enable us to approximate within a certain number of centuries to the time when the Rhone began to form its present delta; but this would not give us the date of the origin of the Leman Lake in its present form, because the river may have flowed into it for thousands of years, without importing any sediment whatever. Such would have been the case, if the waters had first passed through a chain of upper lakes; and that this was actually the fact, seems indicated by the course of the Rhone between Martigny and the Lake of Geneva, and, still more decidedly, by the channels of many of its principal feeders.

If we ascend, for example, the valley through which the Dranse flows, we find that it consists of a succession of basins, one above the other, in each of which there is a wide expanse of flat alluvial lands, separated from the next basin by a rocky gorge, once perhaps the barrier of a lake. The river seems to have filled these lakes, one after the other, and to have partially cut through the barriers, some of which it is still gradually eroding to a greater depth. Before, therefore, we can pretend even to hazard a conjecture as to the era at which the principal delta of Lake Leman or any other delta commenced, we must be thoroughly acquainted

with the geographical features and geological history of the whole system of higher valleys which communicate with the main stream, and all the changes which they have undergone since the last series of convulsions which agitated and altered the face of the country.

Playfair, in his 'Illustrations of the Huttonian Theory of the Earth,' after declaring that he agreed in opinion with the Scotch geologist that the principal valleys of the Alps and other mountains had been excavated by rivers, frankly admits that the Lake of Geneva seems to offer an objection to that theory. The valley above is so deep and broad, that the materials removed from it ought to have filled up the lake again and again 'on any reasonable supposition concerning its original magnitude.' What has become of all the materials which the Rhone has brought down from the higher region? To explain away the difficulty, he suggests, among other hypotheses, that the lake had no existence while the river was eroding the valley above. Part, both of the rising and sinking of the land, he observes, has happened within periods comparatively modern. 'The elevations and depressions may not be the same for every spot; they may be partial, and one part of a stratum or body of strata may rise to a greater height or be more depressed than another. It is not impossible that this process may affect the depth of lakes and change the relative level of their sides and bottom.'* 'The Vallais,' he also adds, 'which we consider as the work of the Rhone, may not have owed all its inequalities to the running of water. It may, when the Alps rose out of the sea, have included many depressions of the surface which the river joined together, and from being a series of lakes formed into one great valley.'† A suggestion has lately been made, that the rock-basin which the Lake of Geneva fills may have been scooped out by ice. That it was once occupied by a glacier I fully admit, but that the action of the glacier hollowed out the cavity is an hypothesis which appears to me quite untenable, for reasons which I have explained elsewhere.‡

* Playfair. Illustrations of Huttonian Theory, p. 366.

† Ibid. p. 367.

‡ Elements of Geology, edition of 1865, p. 170; and Student's Elements, p. 160.

Lake Superior.—Lake Superior is the largest body of fresh water in the world, being above 1,700 geographical miles in circumference when we follow the sinuosities of its coasts, and its length, on a curved line drawn through its centre, being more than 400, and its extreme breadth above 150 geographical miles. Its surface is nearly as large as the whole of England proper. Its average depth varies from 80 to 150 fathoms; but, according to Captain Bayfield, there is reason to think that its greatest depth would not be overrated at 200 fathoms, so that its bottom is, in some parts, nearly 600 feet below the level of the Atlantic, its surface being about as much above it. There are appearances in different parts of this, as of the other Canadian lakes, leading us to infer that its waters formerly occupied a higher level than they reach at present; for at a considerable distance from the present shores, parallel lines of rolled stones and sand are seen rising one above the other, like the seats of an amphitheatre. These ancient lines of shingle are exactly similar to the present beaches in most bays, and they often attain an elevation of 40 or 50 feet, and sometimes several hundred feet above the present level. The heaviest gales of wind do not raise the waters more than three or four feet, and the loose materials, says Agassiz, which lie within the action of heavy storms are entirely deprived of vegetation, whereas the set of beaches next above are covered by a few cryptogamous and herbaceous plants. At a still higher level, and retreating more and more from the shores, are terraces on which grow shrubs and small trees, and above these older beaches are precipitous banks cut out of loose materials, which must have been worn for a considerable time by the action of the waves. Six; ten, and even fifteen such terraces may sometimes be distinguished one above the other. All these beaches and terraces are composed of remodelled glacial drift, the stones having lost more or less of their scratches and polished appearance, and having been rolled into ordinary pebbles. M. Agassiz, when discussing the question how so many changes may have been produced in the level of the old shore of the lake, inclines to the opinion that the land has

risen unequally, rather than that the waters have been repeatedly lowered by the successive wearing down or removal of the barrier on the side where it is lowest at present.* If we are compelled to grant that such inequalities of movement have occurred in Post-glacial times, we may well suppose that others of far greater extent contributed, before and during the Glacial Period, to form the basin of the great lake itself.

The streams which discharge their waters into Lake Superior, without reckoning many of smaller size, are several hundred in number; and the quantity of water supplied by them is many times greater than that discharged at the Falls of St. Mary, the only outlet. The evaporation, therefore, is very great, and such as might be expected from so vast an extent of surface. On the northern side, which is encircled by mountains of old crystalline rock, the rivers sweep in many large boulders with smaller gravel and sand, chiefly composed of granitic and trap rocks. There are also currents in the lake in various directions, caused by the continual prevalence of strong winds, and to their influence we may attribute the diffusion of finer mud far and wide over great areas; for by numerous soundings made during Capt. Bayfield's survey, it was ascertained that the bottom consists generally of a very adhesive clay, containing shells of the species at present existing in the lake. When exposed to the air, this clay immediately becomes so indurated as to require a smart blow of the hammer to break it. It effervesces slightly with diluted nitric acid, and is of different colours in different parts of the lake; in one district blue, in another red, and in a third white, hardening into a substance resembling pipeclay.† From these statements, the geologist will not fail to remark how closely these recent lacustrine formations in America resemble the tertiary argillaceous and calcareous marls of lacustrine origin in Central France. In both cases many of the genera of shells most abundant, as Lymnea and Planorbis, are the same; and in regard to other

* Agassiz, Lake Superior, p. 416.

† Trans. of Lit. and Hist. Soc. of Quebec, vol. i. p. 5. 1829.

classes of organic remains there must be the closest analogy, as I shall endeavour more fully to explain when speaking of the imbedding of plants and animals in recent deposits.

DELTAS OF INLAND SEAS.

Having thus briefly considered some of the lacustrine deltas now in progress, we may next turn our attention to those of inland seas.

Deltas of the Po and Adige.—The Po affords an instructive example of the manner in which a great river bears down to the sea the matter poured into it by a multitude of tributaries descending from lofty chains of mountains. It has been calculated by Mr. Geikie that this river removes one foot of rock from the general surface of its basin in 729 years.* The changes gradually effected in the great plain of Northern Italy since the time of the Roman republic are considerable. Extensive lakes and marshes have been gradually filled up, as those near Placentia, Parma, and Cremona, and many have been drained naturally by the deepening of the beds of rivers Deserted river-courses are not unfrequent, as that of the Serio Morto, which formerly fell into the Adda, in Lombardy. The Po also itself has often deviated from its course, having, after the year 1390, deserted part of the territory of Cremona, and invaded that of Parma; its old channel being still recognisable, and bearing the name of Po Morto. There is also an old channel of the Po in the territory of Parma, called Po Vecchio, which was abandoned in the twelfth century, when a great number of towns were destroyed.

To check these and similar aberrations, a general system of embankment has been adopted; and the Po, Adige, and almost all their tributaries, are now confined between high artificial banks. The increased velocity acquired by streams thus closed in, enables them to convey a much larger portion of foreign matter to the sea; and, consequently, the deltas of the Po and Adige have gained far more rapidly on the Adriatic since the practice of embankment became almost universal. But, although more sediment is borne to the sea,

* Trans. Geol. Soc. of Glasgow, 1868, vol. iii. p. 164.

part of the sand and mud, which in the natural state of things would be spread out by annual inundations over the plain, now subsides in the bottom of the river-channels; and their capacity being thereby diminished, it is necessary, in order to prevent inundations in the following spring, to extract matter from the bed, and to add it to the banks of the river. Hence it happens that these streams now traverse the plain on the top of high mounds, like the waters of aqueducts, and at Ferrara the surface of the Po has become more elevated than the roofs of the houses.* The magnitude of these barriers is a subject of increasing expense and anxiety, it having been sometimes found necessary to give an additional height of nearly one foot to the banks of the Adige and Po in a single season.

The practice of embankment was adopted on some of the Italian rivers as early as the thirteenth century; and Dante, writing in the beginning of the fourteenth, describes, in the seventh circle of hell, a rivulet of tears separated from a burning sandy desert by embankments 'like those which, between Ghent and Bruges, were raised against the ocean, or those which the Paduans had erected along the Brenta to defend their villas on the melting of the Alpine snows.'

Quale i Fiamminghi tra Guzzante e Bruggia,
  Temendo il fiotto che in ver lor s' avventa,
  Fanno lo schermo, perchè il mar si fuggia;
E quale i Padovan lungo la Brenta,
  Per difender lor ville e lor castelli,
  Anzi che Chiarentana il caldo senta.

Inferno, Canto XV.

In the Adriatic, from the northern part of the Gulf of Trieste, where the Isonzo enters, down to the south of Ravenna, there is an uninterrupted series of recent accessions of land, more than 100 miles in length, which within the last 2,000 years has increased from *two to twenty miles in breadth*. A line of sand-bars of great length has been formed nearly all along the western coast of this gulf, inside of which are lagunes, such as those of Venice, and the large lagune of Comacchio, 20 miles in diameter. Newly

* Prony, see Cuvier, Disc. prélim. p. 146.

deposited mud brought down by the streams is continually lessening the depth of the lagunes, and converting part of them into meadows.* The Isonzo, Tagliamento, Piave, Brenta, Adige, and Po, besides many other inferior rivers, contribute to this advance of the coast-line and to the shallowing of the lagunes and the gulf.

The Po and the Adige may now be considered as entering by one common delta, for two branches of the Adige are connected with arms of the Po, and thus the principal delta has been pushed out beyond those bars which separate the lagunes from the sea. The rate of the advance of this new land has been accelerated, as before stated, since the system of embanking the rivers became general, especially at that point where the Po and Adige enter. The waters are no longer permitted to spread themselves far and wide over the plains, and to leave behind them the larger portion of their sediment. Mountain torrents also have become more turbid since the clearing away of forests, which once clothed the southern flanks of the Alps. It is calculated that the mean rate of advance of the delta of the Po on the Adriatic between the years 1200 and 1600 was 25 yards or metres a year, whereas the mean annual gain from 1600 to 1804 was 70 metres.†

Adria was a seaport in the time of Augustus, and had, in ancient times, given its name to the gulf; it is now about twenty Italian miles inland. Ravenna was also a seaport, and is now about four miles from the main sea. Yet even before the practice of embankment was introduced, the alluvium of the Po advanced with rapidity on the Adriatic; for Spina, a very ancient city, originally built in the district of Ravenna, at the mouth of a great arm of the Po, was, so early as the commencement of our era, eleven miles distant from the sea.‡

But although so many rivers are rapidly converting the Adriatic into land, it appears, by the observations of M. Morlot, that since the time of the Romans there has been a

* See De Beaumont, Géologie pratique, vol. i. p. 323. 1844.

† Prony, cited by Cuvier, Discours prélim.

‡ Brocchi, Conch. Foss. Subap. vol. i. p. 118.

general subsidence of the coast and bed of this sea in the same region to the amount of five feet, so that the advance of the new-made land has not been so fast as it would have been had the level of the coast remained unaltered. The signs of a much greater depression anterior to the historical period have also been brought to light by an Artesian well, bored at Venice in 1847, to the depth of more than 400 feet, which still failed to penetrate through the modern fluviatile deposit. The auger passed chiefly through beds of sand and clay, but at four several depths, one of them very near the bottom of the excavation, it pierced beds of turf, or accumulations of vegetable matter, precisely similar to those now formed superficially on the extreme borders of the Adriatic. Hence we learn that a considerable area of what was once land has sunk down 400 feet in the course of ages.*

The greatest depth of the Adriatic, between Dalmatia and the mouths of the Po, is twenty-two fathoms; but a large part of the Gulf of Trieste and the Adriatic, opposite Venice, is less than twelve fathoms deep. Farther to the south, where it is less affected by the influx of great rivers, the gulf deepens considerably. Donati, after dredging the bottom, discovered the new deposits to consist partly of mud and partly of rock, the rock being formed of calcareous matter, incrusting shells. He also ascertained that particular species of testacea were grouped together in certain places, and were becoming slowly incorporated with the mud or calcareous precipitates.† Olivi, also, found some deposits of sand, and others of mud, extending half-way across the gulf; and he states that their distribution along the bottom was evidently determined by the prevailing current.‡ It is probable, therefore, that the finer sediment of all the rivers at the head of the Adriatic may be intermingled by the influence of the current; and all the central parts of the gulf may be considered as slowly filling up with horizontal deposits, similar to those of the Subapennine hills, and containing many of the same species of shells. The Po merely introduces at present fine

* Archiac, Histoire des Progrès de la Géol. 1848, vol. ii. p. 232.

† Brocchi, Conch. Foss. Subap. vol. i. p. 39.

‡ Ibid. vol. ii. p. 94.

sand and mud, for it carries no pebbles farther than the spot where it joins the Trebia, west of Piacenza. At the northern borders of the Gulf of Trieste, the Isonzo, Tagliamento, and many other streams, are forming immense beds of sand and some conglomerate; for here some high mountains of Alpine limestone approach within a few miles of the sea.

In the time of the Romans, the hot baths of Monfalcone were on one of several islands of Alpine limestone, between which and the mainland, on the north, was a channel of the sea, about a mile broad. This channel is now converted into a grassy plain, which surrounds the islands on all sides. Among the numerous changes on this coast, we find that the present channel of the Isonzo is several miles to the west of its ancient bed, in part of which, at Ronchi, the old Roman bridge which crossed the Via Appia was lately found buried in fluviatile silt.

Marine delta of the Rhone.—The lacustrine delta of the Rhone in Switzerland has already been considered (p. 413), its contemporaneous marine delta may now be described. Scarcely has the river passed out of the Lake of Geneva before its pure waters are again filled with sand and sediment by the impetuous Arve, descending from the highest Alps, and bearing along in its current the granitic sand and impalpable mud annually brought down by the glaciers of Mont Blanc. The Rhone afterwards receives vast contributions of transported matter from the Alps of Dauphiny, and the primary and volcanic mountains of Central France; and when at length it enters the Mediterranean, it discolours the blue waters of that sea with a whitish sediment, for the distance of between six and seven miles, throughout which space the current of fresh water is perceptible.

Strabo's description of the delta is so inapplicable to its present configuration, as to attest a complete alteration in the physical features of the country since the Augustan age. It appears, however, that the head of the delta, or the point at which it begins to ramify, has remained unaltered since the time of Pliny, for he states that the Rhone divided itself at Arles into two arms. This is the case at present; one of the branches, the western, being now called Le Petit Rhône,

which is again subdivided before entering the Mediterranean. The advance of the base of the delta, in the last eighteen centuries, is demonstrated by many curious antiquarian monuments. The most striking of these is the great and unnatural détour of the old Roman road from Ugernum to Béziers (*Bœterrœ*), which went round by Nismes (*Nemausus*). It is clear that, when this was first constructed, it was impossible to pass in a direct line, as now, across the delta, and that either the sea or marshes intervened in a tract now consisting of terra firma.* Astruc also remarks, that all the places on low lands, lying to the north of the old Roman road between Nismes and Beziers, have names of Celtic origin, evidently given to them by the first inhabitants of the country; whereas, the places lying south of that road, towards the sea, have names of Latin derivation, and were clearly founded after the Roman language had been introduced.

Another proof, also, of the great extent of land which has come into existence since the Romans conquered and colonised Gaul, is derived from the fact, that the Roman writers never mention the thermal waters of Balaruc in the delta, although they were well acquainted with those of Aix, and others still more distant, and attached great importance to them, as they invariably did to all hot springs. The waters of Balaruc, therefore, must have formerly issued under the sea —a common phenomenon on the borders of the Mediterranean; and on the advance of the delta they continued to flow out through the new deposits.

Among the more direct proofs of the increase of land, we find that Mese, described under the appellation of Mesua Collis by Pomponious Mela,† and stated by him to be nearly an island, is now far inland. Notre-Dame des Ports, also, was a harbour in 898, and is now two leagues from the shore. Psalmodi was an island in 815, and is now two leagues from the sea. Several old lines of towers and sea-marks occur at different distances from the present coast, all indicating the successive retreat of the sea, for each line has in its turn

* Mém. d'Astruc, cited by Von Hoff, vol. i. p. 288.
† Lib. ii. c. v.

become useless to mariners; which may well be conceived when we state that the Tower of Tignaux, erected on the shore so late as the year 1737, is already a mile remote from it.*

By the confluence of the Rhone and the currents of the Mediterranean, driven by winds from the south, sand-bars are often formed across the mouths of the river: by these means considerable spaces become parted off from the sea, and subsequently from the river also, when it shifts its channels of efflux. As some of these lagunes are subject to the occasional ingress of the river when flooded, and of the sea during storms, they are alternately salt and fresh. Others, after being filled with salt water, are often lowered by evaporation till they become more salt than the sea; and it has happened, occasionally, that a considerable precipitate of chloride of sodium has taken place in these natural salterns. During the latter part of Napoleon's career, when the excise laws were enforced with extreme rigour, the police was employed to prevent such salt from being used. The fluviatile and marine shells inclosed in these small lakes often live together in brackish water; but the uncongenial nature of the fluid usually produces a dwarfish size, and sometimes gives rise to strange varieties in form and colour.

Captain Smyth, in his survey of the coast of the Mediterranean, found the sea, opposite the mouth of the Rhone, to deepen gradually from four to forty fathoms, within a distance of six or seven miles, over which the discoloured fresh water extends. The inclination of the new deposits must be too slight to be appreciable, the slope being about a tenth of that already mentioned in the Lake of Geneva (p. 413), which would appear to the eye, in sections of the length usually exhibited in quarries, as horizontal. When the wind blew from the south-west, the ships employed in the survey were obliged to quit their moorings; and when they returned, the new sand-banks in the delta were found covered over with a great abundance of marine shells. By this means we learn how occasional beds of drifted marine shells may become interstratified with fresh-water strata at a river's mouth.

* Bouche, Chorographie et Hist. de Provence, vol. i. p. 23, cited by Von Hoff, vol. i. p. 290.

Stony nature of its deposits.—That a great proportion, at least, of the new deposit in the delta of the Rhone consists of *rock*, and not of loose incoherent matter, is perfectly ascertained. In the Museum at Montpelier is a cannon taken up from the sea near the mouth of the river, imbedded in a crystalline calcareous rock. Large masses, also, are continually taken up of an arenaceous rock, cemented by calcareous matter including multitudes of broken shells of recent species. The observations in the nineteenth century made on this subject corroborate the former statement of Marsilli in the eighteenth, that the earthy deposits of the coast of Languedoc form a stony substance, for which reason he ascribes a certain bituminous, saline, and glutinous nature to the substances brought down with sand by the Rhone.* If the number of mineral springs charged with carbonate of lime which fall into the Rhone and its feeders in different parts of France be considered, we shall feel no surprise at the lapidification of the newly deposited sediment in this delta. It should be remembered, that the fresh water introduced by rivers being lighter than the water of the sea, floats over the latter, and remains upon the surface for a considerable distance. Consequently it is exposed to as much evaporation as the waters of a lake; and the area over which the river water is spread, at the junction of great rivers and the sea, may well be compared, in point of extent, to that of considerable lakes.

Now, it is well known, that so great is the quantity of water carried off by evaporation in some lakes, that it is nearly equal to the water flowing in; and in some inland seas, as the Caspian, it is quite equal. We may, therefore, well suppose that, in cases where a strong current does not interfere, the greater portion not only of the matter held mechanically in suspension, but of that also which is in chemical solution, may be precipitated at no great distance from the shore. When these finer ingredients are extremely small in quantity, they may only suffice to supply crustaceous animals, corals, and marine plants, with the earthy particles necessary for their secretions; but whenever it is in excess (as generally happens if the basin of a river lie partly in a district of active

* Hist. phys. de la Mer.

or extinct volcanos), then will solid deposits be formed, and the shells will at once be included in a rocky mass.

Deposits on the coast of Asia Minor.—Examples of the advance of the land upon the sea are afforded by the southern coast of Asia Minor. Admiral Sir F. Beaufort has pointed out in his survey the great alterations effected since the time of Strabo, where havens are filled up, islands joined to the mainland, and where the whole continent has increased many miles in extent. Strabo himself, on comparing the outline of the coast in his time with its ancient state, was convinced, like our countryman, that it had gained very considerably upon the sea. The new-formed strata of Asia Minor consist *of stone*, not of loose incoherent materials. Almost all the streamlets and rivers, like many of those in Tuscany and the south of Italy, hold abundance of carbonate of lime in solution, and precipitate travertin, or sometimes bind together the sand and gravel into solid sandstones and conglomerates; every delta and sand-bar thus acquires solidity, which often prevents streams from forcing their way through them, so that their mouths are constantly changing their position.*

Delta of the Nile.—That Egypt was 'the gift of the Nile,' was the opinion of her priests before the time of Herodotus; and there can be no doubt that the fertility of the alluvial plain above Cairo, and the very existence of the delta below that city, are due to the action of the great river, or to its power of transporting mud from the interior of Africa, and depositing it on its inundated plains, as well as on that space which has been reclaimed from the Mediterranean, and converted into land.

The depth of the Mediterranean is about twelve fathoms at a small distance from the shore of the delta; it afterwards increases gradually to 50, and then suddenly descends to 380 fathoms. We learn from Lieut. Newbold that nothing but the finest and lightest ingredients reach the Mediterranean, where he has observed the sea discoloured by them to the distance of 40 miles from the shore.† The small

* Karamania, or a brief description of the Coast of Asia Minor, &c. London, 1817.

† Quart. Journ. Geol. Soc. 1848, vol. iv. p. 342.

progress of the delta in the last 2,000 years affords, perhaps, no measure for estimating its rate of growth before it had encroached so much upon the coast-line of the Mediterranean. A powerful current now sweeps along the shores of Africa, from the Straits of Gibraltar to the prominent convexity of Egypt, the western side of which is continually the prey of the waves; so that not only are fresh accessions of land checked, but ancient parts of the delta are carried away. By this cause Canopus and some other towns have been overwhelmed. The marine current alluded to is caused by the prevalence for nine months of the year of winds from the north-west, but they turn in the opposite direction whenever, during the remaining months, a wind sets in from the east. Another reason, however, for the slow advance of the delta for the last two or three thousand years, is the slow subsidence of the land, to which allusion will be made in the sequel.

The Nile for the last 1,500 miles of its course is not joined by a single tributary, great or small; a geographical peculiarity exhibited by no other river in the world. In Nubia, however, during violent thunderstorms, temporary torrents are sometimes formed, some of them as low down as between the first and second cataracts, which wash gravel, sand, and mud into the Nile. The winds also blow clouds of sand into it from the desert where the valley is narrow above the first cataract. About 100 miles above Cairo, or 200 from the sea, the average width of the valley is about five miles, and I am informed by the Rev. Barham Zincke, who has lately returned from Egypt, that the bluffs which bound the plain on the east and west, are composed, some of them of limestone and some of sandstone, and are about 400 feet high. In sailing up the stream for about 450 miles, sometimes the eastern and sometimes the western bluff is in sight, and they conveyed to him the appearance of having been cut by the Nile, as if the river had excavated its own valley. But when we arrive at the first cataract at Assouan, the rocks, being formed of granite, seem to have afforded greater resistance to the erosive power of the river, which then flows through a narrow gorge instead of a wide alluvial plain.

In passing through so many degrees of latitude exposed to a hot sun and to arid winds blowing from the surrounding deserts, the river loses much of its water by evaporation, especially where it is spread out over the plains during the season of inundation, which lasts about four months. The sediment annually left behind on the plain consists of an extremely thin film of matter, most of the mud being thrown down on the banks, which here, as in all other great rivers, are higher than the flat region between them and the heights bounding the valley on each side, so that during the flood season the banks are seen alone emerging above the waters, and forming two long narrow strips of land. The base of the delta is more than 200 miles in length, if we include in it all that part of the coast which intervenes between the ancient extreme eastern and western arms; but these are blocked up at present, and that part of the coast-line, about 90 miles in length, which extends from the Rosetta to the Damietta branches is the only portion now usually called the Delta. The diameter of this low tract from south to north, or from the coast to the head of the delta near Cairo (or to the ancient site of Memphis, thirty miles distant), is about 100 miles. In this region the rate of the deposition of sediment is considerably less than in the alluvial plain above, owing to the wide spread of the waters east and west. The height of the river at Assouan or the ancient Philæ, where the first cataract occurs, is 300 feet above its level at Cairo, a distance of 555 statute miles, following the course of the river, which gives an average fall of rather more than half a foot (6·486 inches) per mile; but the fall between the head of the delta and the sea is much less considerable. According to Sir J. G. Wilkinson, the alluvial matter formed in 1,700 years on the land about Elephantine, or near the first cataract, lat. 24° 5′, is about 9 feet in thickness; at Thebes, lat. 25° 43′, about 7 feet in the same period; and at Heliopolis and Cairo, lat. 30°, about 5 feet 10 inches; and the amount is considerably less at Rosetta and the other mouths of the Nile, lat. 31° 30′.

The bed of the Nile always keeps pace with the general elevation of the soil of Egypt, and the river-banks, like

those of the Mississippi and its tributaries (see p. 439), are much higher than the flat land at a distance, so that they are seldom covered, as before mentioned (p. 429), during the highest inundations. In consequence of the gradual rise of the river's bed, the annual flood is continually spreading over a wider area, and the alluvial soil encroaches on the desert, covering, to the depth of several feet or yards, the base of statues and temples which the waters never reached 3,000 years ago. Although the sands of the Libyan deserts have in some places been drifted into the valley of the Nile, yet these aggressions, says Wilkinson, are far more than counterbalanced by the fertilising effect of the water which now reaches farther inland towards the desert, so that the number of square miles of arable soil is greater at present than at any previous period.

The composition of the Nile-mud resembles very closely that of the Loess or old inundation mud of the Rhine. The following careful analysis is given of it by Lassaigne:* Silica, 42·50; alumina, 24·25; carbonate of lime, 3·85; peroxide of iron, 13·65; magnesia, 1·05; carbonate of magnesia, 1·20; humic acid, 2·80; water, 10·70. It was shown by recent borings, which will presently be mentioned, to be very generally devoid of stratification, except near the margin of the valley, where violent winds have blown quartzose sand from the adjacent deserts, so as to cause alternations of sand and loam in thin layers. It is also stated that around Cairo, where artificial excavations have been made, or in other places where the river has undermined its banks, the mud is divided into layers of different colours, each of them not exceeding a sheet of thin pasteboard in thickness.

The late Mr. L. Horner, F.R.S., was of opinion that the general absence of all indication of successive deposition might be attributed to the extreme thinness of the layer of matter annually thrown down on the greater part of the alluvial plain. The tenuity of this layer is such as not to average, according to the best observers, six inches in a century. The new superficial deposit, which is added to a soil already softened by a submergence of several months

* Quart. Geol. Journ. 1849, vol. v. p. 20. Memoirs.

must be indistinguishable from it. Deep shrinkage cracks are formed both in the new and old soil, where they have been exposed to a hot sun, and into these is drifted dust, raised in clouds by the winds. The action also of worms, insects, and the roots of plants, must be added to these disturbing causes, so that it is evident that no distinction can be left between the deposits of two successive years, even at points where the labours of the agriculturist have not intervened to annihilate all lines of separation.

As the pyramids and other monuments of Egypt carry us back to prehistoric times of more ancient date than do any equally authentic memorials yet known in other lands, it is there, if anywhere, that we may hope to obtain data for estimating roughly at least the number of years which have been required to bring about a given amount of change in the alluvial plain of a great river.

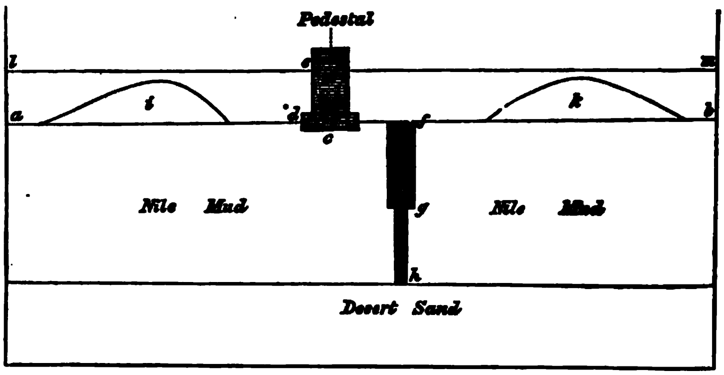
Herodotus observes, 'that the country round Memphis seemed formerly to have been an arm of the sea gradually filled by the Nile, in the same manner as the Meander, Achelous, and other streams, had formed deltas. Egypt, therefore,' he says, 'like the Red Sea, was once a long narrow bay, and both gulfs were separated by a small neck of land. If the Nile,' he adds, 'should by any means have an issue into the Arabian Gulf, it might choke it up with earth in 20,000 or even, perhaps, in 10,000 years; and why may not the Nile have filled a still greater gulf with mud in the space of time which has passed before our age?'*

Mr. Horner suggested to the Royal Society in 1850, that they should have excavations and borings made in the alluvial plain of the Nile, with a view of ascertaining the thickness of the mud which had accumulated round the base of the obelisk at Heliopolis and the pedestal of the statue of Rameses at Memphis, the object being to obtain a chronometric scale, by ascertaining what thickness of sediment had been formed in a given time, and applying that scale for measuring the antiquity of similar mud previously thrown down on the site of those monuments before their erection. The most important result was obtained from an

* Euterpe, XI.

excavation and boring made near the base of the pedestal of the colossal statue of Rameses, the middle of whose reign, according to Lepsius, was 1361 years B.C. Assuming with Mr. Horner* that the lower part of the platform or foundation *c* (fig. 36) was 14¾ inches below the surface of the ground, or alluvial flat *a b*, at the time it was laid, there had been formed between that period and the year A.D. 1850, or

Fig. 36.



Section to explain the thickness of Nile mud on the site of the pedestal of the statue of Rameses at Memphis.

a b. Supposed level of the great Plain when the foundation of the pedestal was laid.
c. Level of lowest part of foundation of pedestal.
d e. Thickness of mud accumulated since the erection of the pedestal.
f g. Shaft, 16 ft. deep, sunk near the pedestal.
g h. Boring carried down 14 ft. below the bottom of the shaft to the junction of the Nile mud with the underlying desert sand.
i k. Mounds thrown up to protect the area of the Temple from the inundations of the Nile.
l m. Present level of the alluvial plain of the Nile.

during a space of 3,211 years, a deposit of 9 feet 4 inches from *d* to *e* round the pedestal, which gives a mean increase of 3½ inches in a hundred years. It was further ascertained, by sinking a shaft *f g* near the pedestal, and by a boring in the same place carried to the additional depth *g h*, that below the level of the old plain *a b* the thickness of old Nile

* Horner, On Alluvial Land of Egypt, Phil. Trans. part i. for 1855.

mud *f h* resting on desert sand amounted to 32 feet; and it was therefore inferred by Mr. Horner that the lowest layer at *h* (in which a fragment of burnt brick was found) was more than 13,000 years old, or was deposited 13,496 years before the year 1850, when the boring was made.

The date of the reign of Rameses has been a matter of discussion; but even if antiquaries should differ by a few centuries, the era fixed by Lepsius may be taken as a sufficient approximation to the truth to be available for the object here proposed.

To this mode of computation it was objected by Mr. Samuel Sharpe, that the Egyptians were in the habit of enclosing with embankments such as *i k*, fig. 36, the areas on which they erected temples and statues, so as to exclude the waters of the Nile. Herodotus tells us that in his time those spots from which the Nile waters had in this manner been shut out for centuries appeared sunk, and could be looked down into from the surrounding ground, that ground having been raised by the gradual accumulation of sediment resulting from the annual inundations. The whole thickness therefore *d e* of 9 feet 4 inches of mud in which the pedestal of the statue was buried, instead of indicating 3,215 years, is simply the produce of the much shorter period which has elapsed since Memphis fell into decay, or since the mounds *i k* gave way and allowed the river to inundate the site of the statue. But Sir John Lubbock, in reply to this objection, has truly remarked that what we are really in search of is the extent to which the flat plain of Memphis *l m* has been raised by the accumulation of Nile sediment since the statue was erected, and although the river when it broke through the embankments and washed mud from them into the enclosure might perhaps in a few years raise the enclosed area up to the level of the great plain outside *l m*, yet it could never heighten that area above the general level. The exceptional rapidity of accumulation, observes Sir J. Lubbock, would only be the complement of the exceptional want of deposition which had preceded.*

Mr. A. R. Wallace, on reading my Antiquity of Man, p. 36

* Sir J. Lubbock, The Reader, March 26, 1864.

sent me this same answer to Mr. Sharpe's objection, which had occurred to him independently. The explanation will perhaps remove some of the difficulties which Mr. Franks and other antiquaries experienced in regard to the date assigned by Mr. Horner, in accordance with his scale, to several pieces of sculpture and pottery found at different levels in sinking through the ten feet of soil, *e d*, in which the lower part of the pedestal was buried. It is most desirable, however, that fresh enquiries should be made to extend and verify the observations already so successfully begun by Mr. Horner, with the assistance of a native engineer, Hekekyan Bey, and under the auspices of the Royal Society, liberally assisted by the late Viceroy of Egypt.

In all calculations referring to the growth of alluvial deposits, or to the effects of aqueous denudation, our chief difficulty in geology arises from our inability to measure correctly the accompanying movements of the land. The position of certain tombs near Alexandria, and their present level relatively to the Mediterranean, and the ruins of certain towns half submerged in the Lake Menzaleh, are generally admitted to imply that there has been a sinking of the land in Egypt within the historical period.

The occurrence of former oscillations of level is also attested by the existence, at different heights, from 30 to 100 feet and upwards, above the level of the present alluvial plain, of a succession of terraces composed of fluviatile alluvium. In these Messrs. Adams and Murie have detected fossil shells of the same species as those now inhabiting the waters of the Nile, such as *Ætheria semilunata, Iridina nilotica, Bulimus pullus*, and *Cyrena fluminalis*. The last-mentioned shell is familiar to us as being so common in the ancient or Post-pliocene river-deposits of the Thames, in London and the neighbourhood, in which the bones of a hippopotamus and other extinct animals are found.

Such terraces occur both above and below the first cataract; in one of them, at Kálábshé in Nubia, the molar teeth of a large hippopotamus were obtained, and were identified by the late Dr. Falconer with the species now living in the Nile.

These and other proofs of gradual movements which have occurred in Post-tertiary times, in Egypt, might have been looked for by geologists, after they had come by independent researches to the conclusion, that the northern borders of the Red Sea, and a large part of the Sahara, or, in other words, vast regions east and west of Egypt, had been upraised within the Post-pliocene epoch. On the one side is the Great Desert, formerly submerged beneath the sea, and now laid dry,* with the *Cardium edule* frequently strewn over its surface; on the other side, or to the eastward, are littoral deposits 200 feet high, bordering the western shore of the Red Sea (lat. 28° N.), which are chiefly made up of corals and shells of recent species, indicating a modern conversion of the ancient sea-bottom into land. During such great continental movements we cannot suppose the intervening valley of the Nile to have remained stationary in its level, or that the great river never shifted its position, and never deepened its channel, whether cutting through accumulations of its own mud, or through subjacent rocks of sandstone and granite.

* Elements of Geology, p. 174.

CHAPTER XIX.

REPRODUCTIVE EFFECTS OF RIVERS—*continued.*

DELTAS FORMED UNDER THE INFLUENCE OF TIDES—BASIN AND DELTA OF THE MISSISSIPPI—ALLUVIAL PLAIN—RIVER-BANKS AND BLUFFS—CURVES OF THE RIVER—NATURAL RAFTS AND SNAGS—MUD-LUMPS NEAR THE MOUTHS, AND THEIR PROBABLE ORIGIN—NEW LAKES, AND EFFECTS OF EARTHQUAKES—ANTIQUITY OF THE DELTA—SECTION IN ARTESIAN WELL AT NEW ORLEANS—DELTA OF THE AMAZONS—DELTA OF THE GANGES AND BRAHMAPOOTRA—HEAD OF THE DELTA AND SUNDERBUNDS—ISLANDS FORMED AND DESTROYED—CROCODILES—AMOUNT OF FLUVIATILE SEDIMENT IN THE WATER—ARTESIAN BORING AT CALCUTTA—PROOFS OF SUBSIDENCE—AGE OF THE DELTA—CONVERGENCE OF DELTAS—ORIGIN OF EXISTING DELTAS NOT CONTEMPORANEOUS—GROUPING OF STRATA AND STRATIFICATION IN DELTAS—CONGLOMERATES—CONSTANT INTERCHANGE OF LAND AND SEA.

In the last chapter several examples were given of the deltas of inland seas, where the influence of the tides is almost imperceptible. We may next consider those marine or oceanic deltas, where the tides play an efficient part in the dispersion of fluviatile sediment, as in the Gulf of Mexico, where they exert a moderate degree of force, and in the Bay of Bengal, where they are extremely powerful. In regard to estuaries, which Rennel termed 'negative deltas,' they will be treated of more properly when our attention is specially turned to the operations of tides and currents in the 21st, 22nd, and 23rd chapters. In this case, instead of the land gaining on the sea at the river's mouth, the tides penetrate far inland beyond the general coast-line.

BASIN AND DELTA OF THE MISSISSIPPI.*

Extent of the basin.—The hydrographical basin of the Mississippi displays, on the grandest scale, the action of running water on the surface of a vast continent. This magnificent river rises nearly in the forty-ninth parallel of north latitude, and flows to the Gulf of Mexico in the twenty-ninth—a

course, including its meanders, of more than 3,000 miles. It passes from a cold climate, where the hunter obtains his furs and peltries, traverses the temperate latitudes, and discharges its waters into the sea in the region of rice, the cotton-plant, and the sugar-cane. From near its mouth at the Balize a steamboat may ascend for 2,000 miles with scarcely any perceptible difference in the width of the river. Several of its tributaries, the Red River, the Arkansas, the Missouri, the Ohio, and others, would be regarded elsewhere as of the first importance, and, taken together, are navigable for a distance many times exceeding that of the main stream. The surface drained by the Mississippi and its tributaries is equal in extent to more than half the continent of Europe, or Europe exclusive of Russia, Norway, and Sweden.

No river affords a more striking illustration of the law before mentioned, that an augmentation of volume does not occasion a proportional increase of surface, nay, is even sometimes attended with a narrowing of the channel. The Mississippi is half a mile wide at its junction with the Missouri, the latter being also of equal width; yet the united waters have only, from their confluence to the mouth of the Ohio, a medial width of about half a mile. The junction of the Ohio seems also to produce no increase, but rather a decrease, of surface.* The St. Francis, White, Arkansas, and Red rivers are also absorbed by the main stream with scarcely any apparent increase of its width, although here and there it expands to a breadth of 1½, or even to 2 miles. On arriving at New Orleans, it is somewhat less than half a mile wide. Its depth there is very variable, the greatest at high water being 168 feet. The mean rate at which the whole body of water flows is variously estimated; according to Mr. Forshey the mean velocity of the current at the surface somewhat exceeds 2¼ miles an hour when the water is at a mean height. Messrs. Humphreys and Abbot found at Natchez a velocity of nearly three miles an hour, at the depth of five feet from the surface. For 300 miles above New Orleans the distance measured by the winding river is about twice as great as the distance in a right line. For the

* Flint's Geography, vol. i. p. 142.

first 100 miles from the mouth the rate of fall is 1·80 inch per mile, for the second hundred 2 inches, for the third 2·30, for the fourth 2·57. Messrs. Humphreys and Abbot give about 4½ inches as the average fall per mile from Memphis to the mouth, a distance of 855 miles.

The alluvial plain of the Mississippi begins to be of great width below Cape Girardeau, 50 miles above the junction of the Ohio. At this junction it is about 50 miles broad, south of which it contracts to about 30 miles at Memphis, expands again to 80 miles at the mouth of the White River, and then suffers various contractions and expansions until it reaches the head of the delta, or the point where the Mississippi sends off its highest branch or arm, called the Atchafalaya. The delta has a diameter from N.W. to S.E. of about 200 miles, and a breadth in the opposite direction of about 140. It comprises, according to the survey of 1860, an area of about 12,300 miles, but to this I shall again refer.

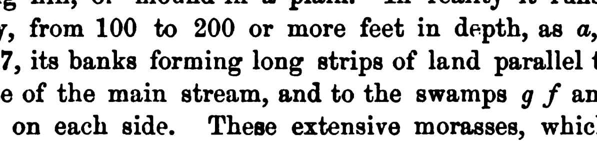
Curves of the Mississippi.—The river traverses the plain in a meandering course, describing immense curves. After sweeping round the half of a circle, it is carried in a rapid current diagonally across the ordinary direction of its channel, to another curve of similar shape. Opposite to each of these, there is always a sand-bar, answering, in the convexity of its form, to the concavity of 'the bend,' as it is called.* The river, by continually wearing these curves deeper, returns, in the manner before described (p. 341), on its own track, so that a vessel in some places, after sailing for twenty-five or thirty miles, is brought round again to within a mile of the place whence it started. When the waters approach so near to each other, it sometimes happens at high floods that they burst through the small tongue of land, and insulate a portion, rushing through what is called the 'cut off,' so that vessels may pass from one point to another in half a mile to a distance which it previously required a voyage of more than twenty miles to reach. As soon as the river has excavated the new passage, bars of sand and mud are formed at the two points of junction with the old bend, which is soon entirely separated from the main

* Flint's Geog. vol. i. p. 152.

river by a continuous mud-bank covered with wood. The old bend then becomes a semicircular lake of clear water, inhabited by large gar-fish (*Lepidostei*), alligators, and wild fowl, which the steamboats have nearly driven away from the main river. A multitude of such crescent-shaped lakes, scattered far and wide over the alluvial plain, the greater number of them to the west, but some of them also eastward of the Mississippi, bear testimony to the extensive wanderings of the great stream in former ages. For the last two hundred miles above its mouth the course of the river is much less winding than above, there being only in the whole of that distance one great curve, that called the 'English Turn.' This greater straightness of the stream is ascribed by Mr. Forshey to the superior tenacity of the banks, which are more clayey in this region.

The Mississippi has been incorrectly described by some of the earlier geographers, as a river running along the top of

Fig. 37.



Section of channel, bank, levees (*a* and *b*), and swamps of Mississippi River.

a long hill, or mound in a plain. In reality it runs in a valley, from 100 to 200 or more feet in depth, as *a*, *c*, *b*, fig. 37, its banks forming long strips of land parallel to the course of the main stream, and to the swamps *g f* and *d e* lying on each side. These extensive morasses, which are commonly well wooded, though often submerged for months continuously, are rarely more than fifteen feet below the summit level of the banks. The banks themselves are occasionally overflowed, but are usually above water for a breadth of about two miles. They follow all the curves of the great river, and near New Orleans are raised artificially by embankments (or levees), of which sections are seen at *a* and *b*, fig. 37, through which the river when swollen sometimes cuts a deep channel (or crevasse), inundating the

adjoining low lands and swamps, and not sparing the lower streets of the great city.

The cause of the uniform upward slope of the river-bank, *d b*, above the adjoining alluvial plain is this: when the waters charged with sediment pass over the banks in the flood season, their velocity is checked among the herbage and reeds, and they throw down at once the coarser and more sandy matter with which they are charged. But the fine particles of mud are carried farther on, so that at the distance of two miles, a thin film of fine clay only subsides, forming a stiff unctuous black soil, which gradually envelops the base of trees growing on the borders of the swamps.

Waste of the banks.—It has been said of a mountain torrent, that 'it lays down what it will remove, and removes what it has laid down;' and in like manner the Mississippi, by the continual shifting of its course, sweeps away, during a great portion of the year, considerable tracts of alluvium, which were gradually accumulated by the overflow of former years, and the matter now left during the spring-floods will be at some future time removed. After the flood season, when the river subsides within its channel, it acts with destructive force upon the alluvial banks, softened and diluted by the recent overflow. Several acres at a time, thickly covered with wood, are precipitated into the stream; and large portions of the islands are frequently swept away.

Captain Hall, writing in 1829, observes that some years before, 'when the Mississippi was regularly surveyed, all its islands were numbered, from the confluence of the Missouri to the sea: but every season makes such revolutions, not only in the number but in the magnitude and situation of these islands, that this enumeration is now almost obsolete. Sometimes large islands are entirely melted away; at other places they have attached themselves to the main shore, or, which is the more correct statement, the interval has been filled up by myriads of logs cemented together by mud and rubbish.'*

Rafts.—One of the most interesting features in the great

* Travels in North America, vol. iii. p. 361.

rivers of this part of America is the frequent accumulation of what are termed 'rafts,' or masses of floating trees, which have been arrested on their progress by snags, islands, shoals, or other obstructions, and made to accumulate, so as to form natural bridges reaching entirely across the stream. One of the largest of these was called the raft of the Atchafalaya, an arm of the Mississippi, which branches off a short distance below its junction with the Red River. The Atchafalaya being in a direct line with the general direction of the Mississippi, catches a large portion of the timber annually brought down from the north; and the drift trees collected in about thirty-eight years previous to 1816 formed a continuous raft, no less than ten miles in length, 220 yards wide, and eight feet deep. The whole rose and fell with the water, yet was covered with green bushes and trees, and its surface enlivened in the autumn by a variety of beautiful flowers. It went on increasing till about 1835, when some of the trees upon it had grown to the height of about sixty feet. Steps were then taken by the State of Louisiana to clear away the whole raft and open the navigation, which was effected, not without great labour, in the space of four years.

The rafts on Red River are equally remarkable; in some parts of its course, cedar trees are heaped up by themselves, and in other places pines. On the rise of the waters in summer hundreds of these are seen, some with their green leaves still upon them, just as they have fallen from a neighbouring bank, others leafless, broken, and worn in their passage from a far distant tributary. Wherever they accumulate on the edge of a sand-bar they arrest the current and soon become covered with sediment. On this mud the young willows and the poplars called cotton-wood spring up, their boughs still farther retarding the stream, and as the inundation rises, accelerating the deposition of new soil. The bank continuing to enlarge, the channel at length becomes so narrow that a single long tree may reach from side to side, and the remaining space is then soon choked up by a quantity of other timber which has become waterlogged and has sunk to the bottom. This raft, say Messrs. Humphreys

and Abbot, formed a dam in 1860, which backed the Red River between twenty and thirty miles, and threw about three-quarters of its water through two natural outlets into Soda Lake, affording a navigation round the right bank of the raft.*

'Unfortunately for the navigation of the Mississippi,' observes Captain Hall, 'some of the largest trunks, after being cast down from the position on which they grew, get their roots entangled with the bottom of the river, where they remain anchored, as it were, in the mud. The force of the current naturally gives their tops a tendency downwards, and by its flowing past, soon strips them of their leaves and branches. These fixtures, called snags, or planters, are extremely dangerous to the steam-vessels proceeding up the stream, in which they lie like a lance in rest, concealed beneath the water, with their sharp ends pointed directly against the bows of the vessels coming up. For the most part these formidable snags remain so still that they can be detected only by a slight ripple above them, not perceptible to inexperienced eyes. Sometimes, however, they vibrate up and down, alternately showing their heads above the surface, and bathing them beneath it.'† So imminent was the danger caused by these snags, that a steamboat was constructed and provided with machinery by which the greater number of these trunks of trees were drawn out of the mud.

The prodigious quantity of wood annually drifted down by the Mississippi and its tributaries is a subject of geological interest, not merely as illustrating the manner in which abundance of vegetable matter becomes, in the ordinary course of nature, imbedded in submarine and estuary deposits, but as attesting the constant destruction of soil and transportation of matter to lower levels by the tendency of rivers to shift their courses. Each of these trees must have required many years, some of them centuries, to attain their full size; the soil, therefore, whereon they grew, after remaining undisturbed for long periods, is ultimately torn up and swept away.

* Humphreys and Abbot, Report of Mississippi Survey, 1861.

† Travels in N. America, vol. iii. p. 362.

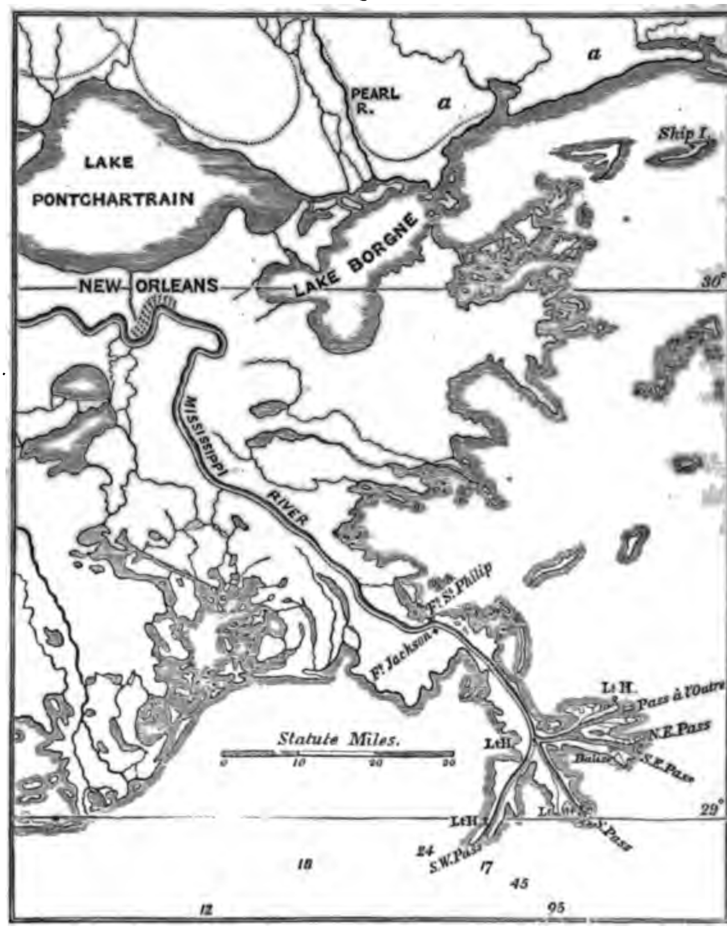
It is also found in excavating at New Orleans, even at the depth of several yards below the level of the sea, that the soil of the delta contains innumerable trunks of trees, layer above layer, some prostrate, as if drifted, others broken off near the bottom, but remaining still erect, and with their roots spreading on all sides, as if in their natural position. In such situations they appeared to me to indicate a sinking of the ground, as the trees must formerly have grown in marshes above the sea-level. In the higher parts of the alluvial plain, for many hundred miles above the head of the delta, similar stools and roots of trees are also seen buried in stiff clay at different levels, one above the other, and exposed to view in the banks at low water. They point clearly to the successive growth of forests in the extensive swamps of the plain, where the ground was slowly raised, year after year, by the mud thrown down during inundations. These roots and stools belong chiefly to the deciduous cypress (*Taxodium distichum*) and other swamp trees, and they bear testimony to the constant shifting of the course of the great river, which is always excavating land originally formed at some distance from its banks.

Mud-lumps off the mouths of the river.—The most southern or seaward part of the delta of the Mississippi is a long narrow tongue of land protruding itself for fifty miles into the Gulf of Mexico, and terminating in several arms or passes, as they are called, which have a fan-shaped arrangement (see map, fig. 38), the south-west pass being that through which all the water is now poured out, while each of the others has, by turns, at some former period, been the principal channel of discharge. The narrow tongue of land above alluded to consists simply of two low banks covered with reeds, young willows, and poplars.

In appearance these banks answer precisely to those of the river in the alluvial plain (see fig. 37, p. 439) when the inundation is at its height, and nothing is seen above water but the upper portions of the banks; but in the one case we have on each side a wide expanse of fresh water interrupted only by the tops of the tallest trees which grow in the swamps,

while in the other we have on each side the salt water of the Gulf of Mexico, of a bluish-green colour.

Fig. 38.



Map of part of the delta of the Mississippi below New Orleans.*

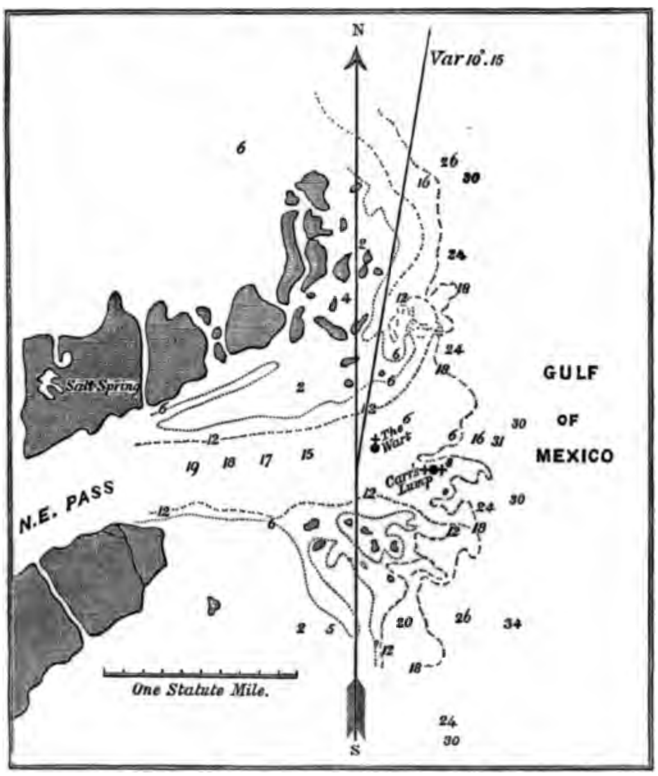
a, a. Post-Pliocene formation, partly marine and partly of cypress-swamp origin, called by Prof. Hilgard 'Coast-Pliocene.'

In this region, where so rapid a conversion is going on from sea into land, a phenomenon occurs which is without parallel,

* Humphreys and Abbot, Report on the Mississippi River, Plate II.

so far as I am aware, in the delta of any other river. I often heard during my visit in 1845 to the pilot station called the Balize, of the swelling up of the muddy bottom of the gulf to the height of several feet, or even yards above the level of high tide, and this in places where there had previously been

Fig. 39.



Map showing the positions of the Wart and Carr's Mud-lumps at the North-east Pass of the Mississippi River, from a survey of Capt. Talcott, in 1839.*

a depth of several fathoms. The pilots told me that these 'mud-lumps,' as they call them, sometimes displayed on their surface the anchors of vessels, and in one instance, a cargo of

* This map and the views of the two mud-lumps were kindly communicated to me by Gen. Humphreys, of the U. S. Engineers.

heavy stones from a vessel which was known to have been wrecked in water ten feet deep. The island of the Balize originated in this manner, and five salt springs were described as rising in it, by certain French surveyors, as long ago as the year 1726.* Mr. Forshey states that, in 1832, a mud-island made its appearance in the middle of which a spring issued. These new islands, as we learn from the subsequent survey of Captain Talcott in 1839, vary from an acre to several acres in extent. The gradual rise of some of them was watched during the survey, from two feet below water to three feet above it, and it was observed that *they were always situated*

Fig. 40.

S. View of Carr's Lump, N.E. Pass.
Extreme height above low water, 8 feet.

off some one of the mouths of the river. They have never been known to make their appearance in that part of the delta where no modern additions are being made to the land. Sometimes they attain a height of 10 or even 18 feet above the level of the sea (see figs. 40, 41). They are composed almost entirely of tenacious mud, usually homogeneous, but occasionally mixed with sand. This mud is chiefly pushed up bodily, but some of it consists of matter brought up by a spring to the top of the dome-shaped mass, and thrown down on the surface on all sides, over which the muddy water

* Thomassy, Bulletin de la Soc. Géol. de France, tome xvii. p. 253. 1859–60.

pours. So much carburetted hydrogen or inflammable gas is emitted, together with salt or brackish water, that Col. Sidell suggests that they deserve the name of gas vents rather than of springs. The tubular cavities up which the springs rise are about 6 inches in diameter, vertical, and as regular in form as if bored by an auger. One which was sounded was found to be 24 feet deep, and the lead at the bottom of the line seemed to be still slowly sinking through thick mud. The springs issue at first from the centre and highest part, and afterwards successively through cracks at

Fig. 41.

S.S.W. View of the Mud-lump called the Wart, N.E. Pass.
Extreme height above low water, 14 feet.

lower and lower levels, and in some of the oldest mud-lumps they have altogether ceased to flow.

During storms, when the surface of the gulf is raised by the prevalence of certain winds, the salt water is blown into the passes, and the waves undermine parts of these mud-lumps. The steepness and occasional verticality of the sides in the Wart and Carr's Lump (figs. 40 and 41) are due to such denuding action. Hurricanes have been known to sweep away an entire mud-lump, or at least such portions of it as

projected above low water. Col. Sidell informs me, that when an excavation was made at New Orleans for the foundation of the Custom House, some years after the survey of 1839, the digging appeared to him to be in the body of an old mud-lump;* and no doubt many such would be found in the older parts of the delta, and they would present a very perplexing enigma to a geologist who had no clue to their mode of origin. We learn from Professor Hilgard† that in 1862 Mr. D. H. Avery found on the coast of Louisiana, at a distance of 140 geographical miles from the mouth of the Mississippi, a deposit of rock-salt of very modern, perhaps post-Tertiary age. It occurred in a little island called Petit Anse, which rises partly from the sea and partly from the coast-marsh. As this salt formation is said to be 144 acres in extent and 38 feet thick, it may perhaps be more or less continuous under the delta and be connected with the salt springs in the island of the Balize mentioned at p. 446. We need feel no surprise at the quantity of gaseous matter disengaged from cracks in these newly raised islands, when we recollect that almost everywhere in Europe, where a successful Artesian boring has been made, the water at first spouts up to a height far beyond that to which it would be carried by simple hydrostatic pressure. A portion of the propelling force usually consists of atmospheric air and carbonic acid gas, which last is generated by the decomposition of animal and vegetable matter. Of the latter there must be always a great store in the recent deposits of a delta like that of the Mississippi, as they enclose much drift timber at all depths, and the pent-up gaseous matter will be ready to escape wherever the overlying impervious clays are upheaved and rent.

Origin of the mud-lumps.—I am informed by Col. Sidell, that when one of the lumps was blown up with gunpowder, a great ebullition of gas, chiefly carburetted hydrogen, took place, and left a crater-shaped hollow. Such gas has also been known to be given out for several years in succession; from which facts the Colonel infers, that when it cannot get vent it may sometimes accumulate to such an amount as to be able to overcome the pressure of the

* Letter to the Author, Oct. 16, 1865.

† American Journ. of Science, vol. xlvii.

incumbent mud, and force it up in the shape of a mud-lump. But this hypothesis leaves unexplained the important fact that the swelling up of the bottom always takes place off what are called 'the passes,' or off the extremity of the delta, near those points where the chief load of fresh sand, gravel, and sediment is thrown down on the muddy bottom of the gulf. The decay of drift timber and other vegetable matter must be going on actively at various depths all over the delta, and often far from the river's mouth; so that it seems to me more probable that the gaseous emanations play only a secondary part, helping to bring up mud from below and deposit it on the slopes of the newly raised mound, as in the eruption of a mud volcano. The initiatory moving power may probably be derived from the downward pressure of the gravel, sand, and sediment accumulated during the flood season off the various mouths or passes, upon a yielding bottom of fine mud and sand. This new deposit, according to Messrs. Humphreys and Abbot, forms annually a mass of no less than one mile square, having a thickness of twenty-seven feet. It consists of mud, coarse sand, and gravel, which the river lets fall somewhat abruptly when it first comes in contact with the still salt water of the gulf. A cubic mass of such enormous volume and weight thrown down on a foundation of yielding mud, consisting of materials which, as being very fine and impalpable, had long before been carried out farthest from the land, may well be conceived to exert a downward pressure capable of displacing, squeezing, and forcing up some parts of the adjoining bottom of the gulf, so as to give rise to new shoals and islands.

Railway engineers are familiar with the swelling up of a peatmoss or the bed of a morass, on some adjoining part of which a new embankment has been constructed. I saw an example of this in the year 1839, in the Loch of Rescobie, in Forfarshire, five miles east of the town of Forfar. That lake had been partially drained, and the railway mound was carried over newly exposed, soft, and swampy ground, which gave way so as to let the mound sink down fifteen feet. It then became necessary to pile up additional matter

fifteen feet thick in order to obtain the required level. On one side of the embankment, the bog, when I visited the place, had swollen up in a ridge 40 feet long and 8 feet high, the upper portion consisting of peaty matter traversed by numerous willow roots. In the highest part of this upraised mass were several irregular cracks about six feet in their greatest width, and open for a depth of two yards or more. On the opposite side of the railway mound, and about 100 yards distant from it in the middle of what remained of the half-drained loch, a new island or 'mud-lump' was seen, which had begun to rise slowly in 1837, and had attained before 1840 a height of several yards, with a length of about 100 feet, and a width of 25 feet. It was still strewed over with dead fresh-water mussels and other shells, but many land plants had already sprung up, so that its surface was green.

In 1852 I saw a remarkable instance of such a downward and lateral pressure, in the suburbs of Boston (U. S.), near the South Cove. With a view of converting part of an estuary overflowed at high tide into dry land, they had thrown into it a vast load of stone (chiefly granite) and sand, upwards of 900,000 cubic yards in volume. Under this weight the mud had sunk down many yards vertically. Meanwhile the adjoining bottom of the estuary, supporting a dense growth of salt-water plants, only visible at low tide, had been forced gradually upward, in the course of many months, so as to project five or six feet above high-water mark. The upraised mass was bent into five or six parallel anticlinal folds, and below the upper layer of turf, consisting of salt-marsh plants, mud was seen above the level of high tide, full of sea-shells, such as *Mya arenaria*, *Modiola plicatula*, *Sanguinolaria fusca*, *Nassa obsoleta*, *Natica triseriata*, and others. In some of these curved beds the layers of shells were quite vertical. The upraised area was 75 feet wide, and several hundred yards long.

Formations of lakes in Louisiana.—Another striking feature in the basin of the Mississippi, illustrative of the changes now in progress, is the formation by natural causes of great lakes, and the drainage of others. These are especially frequent in

the basin of the Red River in Louisiana, where the largest of them, called the Bistineau, is more than thirty miles long, and has a medium depth of from fifteen to twenty feet. In the deepest parts are seen numerous cypress-trees (*Taxodium distichum*) of all sizes, now dead, and most of them with their tops broken by the wind, yet standing erect under water. This tree resists the action of air and water longer than any other, and, if not submerged throughout the whole year, will retain life for an extraordinary period. Lake Bistineau, as well as Black Lake, Cado Lake, Spanish Lake, Natchitoches Lake, and many others, have been formed, according to Darby, by the gradual elevation of the bed of the Red River, in which the alluvial accumulations have been so great as to raise its channel, and cause its waters, during the flood season, to flow up the mouths of many tributaries, and to convert parts of their courses into lakes. In the autumn, when the level of Red River is again depressed, the waters rush back, and some lakes become grassy meadows, with streams meandering through them.* Thus, there is a periodical flux and reflux between Red River and some of these basins, which are merely reservoirs, alternately emptied and filled, like our tide estuaries—with this difference, that in the one case the land is submerged for several months continuously, and in the other twice in every twenty-four hours. It has happened, in several cases, that a raft of timber or a bar has been thrown by the Red River across some of the openings of these channels, and then the lakes become, like Bistineau, constant repositories of water. But, even in these cases, their level is liable to annual elevation and depression, because the flood of the main river, when at its height, passes over the bar; just as, where sandhills close the entrance of an estuary on the Norfolk or Suffolk coast, the sea, during some high tide or storm, has often breached the barrier and inundated again the interior.

The plains of the Red River and the Arkansas are so low and flat, says Mr. Featherstonhaugh, that whenever the Mississippi rises thirty feet above its ordinary level, those

* Darby's Louisiana, p. 33.

great tributaries are made to flow back, and inundate a region of vast extent. Both the streams alluded to contain red sediment, derived from the decomposition of red porphyry; and since 1833, when there was a great inundation in the Arkansas, an immense swamp has been formed near the Mammelle Mountain, comprising 30,000 acres, with here and there lagoons where the old bed of the river was situated; in which are seen standing innumerable trees, for the most part dead, of cypress, cotton-wood, or poplar, the triple-thorned acacia, and others of great size. Their trunks appear as if painted red for about fifteen feet from the ground; at which height a perfectly level line extends through the whole forest, marking the rise of the waters during the last flood.*

Messrs. Humphreys and Abbot mention that the upper part of the Red River lies in a gypseous formation containing much red clay, from which, as well as from the porphyry alluded to by Featherstonhaugh, the colour of the sediment may be derived.†

But most probably the causes above assigned for the recent origin of these lakes are not the only ones. Subterranean movements have altered, so lately as the years 1811–12, the relative levels of various parts of the basin of the Mississippi, ituated 300 miles north-east of Lake Bistineau. In those years the great valley, from the mouth of the Ohio to that of the St. Francis, including a tract 300 miles in length, and exceeding in area the whole basin of the Thames, was convulsed to such a degree as to create new islands in the river, and lakes in the alluvial plain. Some of these were on the left or east bank of the Mississippi, and were twenty miles in extent; as, for example, those named Reelfoot and Obion in Tennessee, formed in the channels or valleys of small streams bearing the same names.

But the largest area affected by the great convulsion lies eight or ten miles to the westward of the Mississippi, and inland from the town of New Madrid, in Missouri. It is

* Featherstonhaugh, Geol. Report. Washington, 1835, p. 84.

† Report on the Mississippi, p. 40.

called 'the sunk country,' and is said to extend along the course of the White Water and its tributaries, for a distance of between seventy and eighty miles north and south, and thirty miles or more east and west. Throughout this area, innumerable submerged trees, some standing leafless, others prostrate, are seen; and so great is the extent of lake and marsh, that an active trade in the skins of musk-rats, mink, otters, and other wild animals, is now carried on there. In March 1846 I skirted the borders of the 'sunk country' nearest to New Madrid, passing along the Bayou St. John and Little Prairie, where dead trees of various kinds, some erect in the water, others fallen, and strewed in dense masses over the bottom, in the shallows, and near the shore, were conspicuous. I also beheld countless rents in the adjoining dry alluvial plains, caused by the movements of the soil in 1811–12, still open, though the rains, frost, and river inundations have greatly diminished their original depth. I observed, moreover, numerous circular cavities, called 'sink holes,' from ten to thirty yards wide, and twenty feet or more in depth, which interrupt the general level of the plain. These were formed by the spouting out of large quantities of sand and mud during the earthquakes.*

That the prevailing changes of level in the delta and alluvial plain of the Mississippi have been caused by the subsidence, rather than the upheaval of land, appears to me established by the fact, that there are no protuberances of upraised alluvial soil, projecting above the level surface of the great plain. It is true that the gradual elevation of that plain, by new accessions of matter, would tend to efface every inequality derived from this source, but we might certainly have expected to find more broken ground in the great plain westward of the Mississippi, had local upthrows of alluvial strata been of repeated occurrence.

In regard to the strata composing the lower part of the great delta, an observation of Darby deserves attention. In the steep banks of the Atchafalaya, before alluded to, the

* For an account of the 'sunk country,' shaken by the earthquake of 1811–1812, see Lyell's Second Visit to the United States, ch. xxxiii.

following section, says he, is observable at low water:—first an upper stratum, consisting invariably of bluish clay, common to the banks of the Mississippi; below this a stratum of red ochreous earth, peculiar to Red River, under which the blue clay of the Mississippi again appears; and this arrangement is constant, proving, as that geographer remarks, that the waters of the Red River occupied alternately, at some former periods, considerable tracts below their present point of union.* Such alternations are probably common in submarine spaces situated between two converging deltas; for, before the two rivers unite, there must almost always be a certain period when an intermediate tract will by turns be occupied and abandoned by the waters of each stream; since it can rarely happen that the season of highest flood will precisely correspond in each. In the case of the Red River and Mississippi, which carry off the waters from countries placed under widely distant latitudes, an exact coincidence in the time of greatest inundation is very improbable.

Antiquity of the delta and alluvial plain.—After I had examined the pilot station called the Balize, near the mouth of the Mississippi, in 1846, I endeavoured to estimate the quantity of sedimentary matter contained in the delta and in the alluvial plain, and to calculate the minimum of time which the river must have required to deposit so vast a mass of matter. The area of the delta was assumed by Mr. Forshey to be about 13,600 square British miles in extent. In the more recent survey of Messrs. Humphreys and Abbot, in 1861, it is taken to be somewhat less, or 12,300 square miles. The average depth of the fluviatile formation in this area I supposed to be somewhat more than 500 feet, and for facility of calculation I assumed it to be 528 feet, or $\frac{1}{10}$ of a mile. My conjectures on this head were founded partly on the depth of the Gulf of Mexico, between the southern point of Florida and the Balize, and partly on borings 600 feet deep, in the delta near Lake Pontchartrain, north of New Orleans, in which the bottom of the alluvial matter was said not to have been reached at that depth—a result confirmed, as we shall

* Darby's Louisiana, p. 103.

presently see, by a more recent experiment. For the quantity of sediment contained in the water I adopted Mr. Riddell's estimate of $\frac{1}{1245}$ in weight, and this does not differ materially from the results obtained by Messrs. Humphreys and Abbot after a long series of careful measurements, for they give the solid contents as $\frac{1}{1321}$.

From the data above stated as to the thickness of the delta-deposits, and the quantity of solid matter brought down annually by the river (which would amount to 3,702,758,400 cubic feet), I inferred that the accumulation of the whole deposit must have taken 67,000 years. But in the course of their survey, Messrs. Humphreys and Abbot came to the conclusion that the quantity of water annually discharged by the Mississippi into the gulf had been greatly underrated. They also remarked that the river pushes along the bottom of its channel even to its mouth a certain quantity of sand and gravel, equal, according to them, to about $\frac{1}{10}$ of the mud held in suspension by the river, of which I had taken no account. Allowing, therefore, for this addition and for the larger discharge of muddy water, they make the whole mass of transported matter nearly double that which I had assumed; consequently the number of years required for the growth of the whole delta would be reduced to about one half, or to about 33,500 years, if my former assumed data as to the probable thickness of the deposit be adopted.

But in 1854* another Artesian well was bored at New Orleans to the depth of 630 feet, through strata containing shells of recent species, without any signs of the foundations of the modern deposit having been reached. The mineral character of the strata pierced through, as given in the report of Messrs. Humphreys and Abbot, will be seen to consist throughout of various coloured clays and sands, with much vegetable matter. One bed of sand at the depth of 582 feet is described as nearly stony, but the rest as unconsolidated. At the depth of 66 feet, cypress roots (*Taxodium distichum*) and waterworn pebbles are mentioned—again at 130 feet bark of the cypress occurred, as I learn from Professor Hilgard,

* Report of Survey of Mississippi River, p. 101.

and at the depth of 153 feet a cedar log in a sound state. All these remains are exactly of such a character as we should expect to find in a formation accumulated in the sea off the mouths of the great river.

General Humphreys has had the kindness, at my request, to submit the shells which were brought up from various depths to Professor Hilgard, author of a valuable report on the geology of the State of Mississippi, and he informs me that in one stratum occurring at the depth of 41 feet in the Artesian boring, and which was composed exclusively of shells, he has found 22 species of mollusca in a determinable state. All of them are of species now living in the gulf, and of which, with one or two exceptions, he has himself collected specimens on the shores of Ship Island, near the mainland (see map, fig. 38, p. 444). They all belong to salt-water genera, such as Mactra, Arca, Cardium, Lucina, Venus, Pandora, Astarte, Donax, Tellina, Oliva, Marginella, Buccinum, Natica, &c. Recent marine shells occurred at intervals as far down as 235 feet, but among the species obtained at that depth were a Tellina and Cardium which Mr. Hilgard has not yet been able to name; he remarks, however, that they do not agree with any of the American Miocene or Eocene species known to him. From much greater depths, and near the bottom of the boring, shells of living species were again identified, and among them *Venus Paphia*, *Arca transversa*, *A. ponderosa*, and *Gnathodon cuneatus*, the latter bivalve being one which swarms in the lagoons of the delta, such as Lake Pontchartrain, in such numbers that the dead shells are used for making roads. Professor Hilgard compares the upper portions of the deposit pierced through, to a formation called by him 'Coast-Pliocene' (which appears to me of Post-Pliocene age), occurring at slight elevations above the sea along the coast of the gulf in the State of Mississippi (see *a*, *a*, map, p. 444). Some beds of this formation he describes as containing the common eatable oyster of America, *O. Virginica*, together with *Mytilus hamatus*, and the living barnacle of that coast, while in other parts it is full of the roots and trunks of the deciduous cypress. As the beds containing these shells are now some feet above the level of the

sea, they bear witness to an upheaval of the bottom of the gulf at a very modern period.

It has already been stated that the base of the marine formation was not reached in the Artesian well at New Orleans at a depth of 630 feet. It will be seen by the map (fig. 38) that at the distance of only twelve miles from the mouth of the South Pass the soundings already give a depth of 95 fathoms. Eight miles farther in the same direction we find 144 fathoms, then at 32 miles 452 fathoms—beyond this 600, and they increase to 1,000 fathoms before we arrive at the Florida Straits. When we consider the manner in which the delta at and below New Orleans protrudes beyond the general coast-line, and that at a distance from the Balize equal to that which separates the Balize from New Orleans, the gulf is 3,000 feet deep, it seems probable that the recent deposit if it could be gauged would prove to be far more than 600 feet thick, and might even attain twice or thrice that thickness. We must be prepared to find that the great bulk of it will contain marine and not fluviatile shells, and that a large part of the whole will consist of fine clay, although here and there pebbles and sand brought down to the bar will have been spread out during storms over wide areas.

In my Second Visit to the United States (vol. ii. p. 154), I have remarked that 'all the pilots agree, that when the Mississippi is at its height, it pours several streams of fresh water, tinged with yellow sediment, for twelve or more miles into the gulf, beyond its mouths. These streams, floating over the heavier salt water, spread out into broad superficial sheets or layers, which the keels of vessels plough through, turning up a furrow of clear blue water, which forms a dark streak in the middle of the ship's wake. We may infer, therefore, that both in the summer, when the swollen river is turbid and depositing mud, and in winter, when the sea is making reprisals on the delta, there is a large amount of sediment dispersed far and wide and carried by currents to the deeper and more distant parts of the gulf.'

We learn from the recent survey of Humphreys and Abbot, that the narrow strip of land formed near the present mouths or passes has been advancing for some time at the rate of

262 feet a year; but this fact supplies us with no data for estimating the rate of growth of the whole delta in past times. On comparing an Admiralty survey map a hundred years old, executed by Captain Gould* between the years 1764 and 1771, with the maps made a hundred years afterwards by the United States surveyors (that by Talcott in 1838, and that of Humphreys and Abbot in 1860), it appears that the land at the South Pass (see map, fig. 38), instead of having advanced, has receded about four miles within the last century. This return of the sea to its old limits is doubtless owing to this pass having ceased to be a great channel of discharge, so that, instead of new additions being made to the banks, there has been a loss even of some of the land that had been gained. The denudation in such cases may not extend to a depth of many feet, but it shows, not only how difficult it is to estimate the average rate of advance of the land by observations made during short periods, but how extensively the coarse materials first thrown down on the bars may subsequently be removed and spread out in thin strata over large spaces. Even if we compare the two American surveys already alluded to, of 1838 and 1860, we find that in this interval of twenty-two years a bank of new land in the Pass à l'Outre, measuring two miles east and west by half a mile north and south, had been lost or cut away by the waves.

In boring vertically through any part of the delta, we may expect to pass occasionally through brackish-water strata, formed in lagoons, and through others containing purely marine shells; and if there have been oscillations in the level of the ground, as may well be supposed in the case of tens of thousands of years, there will be alternations of fluviatile beds and fresh-water cypress-swamps, with clays and sands containing marine shells. On the whole, I am not disposed to regard the estimate which I made in 1846, of the time required for the accumulation of the delta, as extravagant. The rate at which the river accomplishes a given amount of work is no doubt nearly double what I supposed, as shown

* Admiral Richards, of the Hydrographical Office, had the kindness to show me [the or]iginal of this map.

by Messrs. Humphreys and Abbot; but, on the other hand, the quantity of work done, or of mud and sand which has been carried down into the gulf, is far greater than that which I assumed as the basis of my calculation.

We have no information obtained by borings in regard to the thickness of the alluvial deposit in the plain above the delta, the superficial area of which is about equal to that of the delta itself. I assumed it to average half that of the delta, or 264 feet. I grounded this conclusion partly on the idea that the valley had been subsiding, as a part of it sank during the earthquake of New Madrid in 1811–12, and partly on the fact that the Mississippi is continually shifting its course in the great alluvial plain, cutting its channel to the depth of 100 feet, and sometimes even to 250 feet,—filling up on one side as much space as it scoops out on the other; and these changes alone must, I think, have given a considerable depth to the alluvial deposit, independently of the filling up of the original basin of the great river, the capacity of which was probably increased by repeated subsidences.

If we ascend the Mississippi for 165 miles above New Orleans, we find at Port Hudson, on the east or left bank of the river, a cliff continually undermined by the stream. This cliff I examined in 1846, and the state of it had been well described sixty-nine years before by Bartram the botanist. At the base of it, about forty feet above the level of the gulf, is a buried forest, with the stools and roots in their natural position, and composed of such trees as now live in the swamps of the delta and alluvial plain, the deciduous cypress being the most conspicuous of them. Above this buried forest the bluff rises to a height of about 75 feet, and it affords a section of beds of river-sand, including trunks of trees and pieces of drift wood, and above the sand a brown clay. From the top of the cliff the ground slopes to a height of 150 feet above the level of the buried forest, or about 200 feet above the sea. From this section we learn that there have been great movements and oscillations of level since the Mississippi began to form an alluvial plain, and to drift down timber into it, and to bury under its sand and sediment ancient forests, resembling those which now flourish in the swamps of its

plain and delta. When the trees were buried, the ground was probably sinking, after which it must have been raised again, so as to allow the stream to cut through its old alluvium. The depth of this ancient fluviatile formation is seen to be no less than 200 feet, without any signs of the bottom being reached. In character it is identical with the deposit called Coast-Pliocene by Prof. Hilgard (see p. 456, and *a*, *a*, map, p. 444), of which, I presume, it is a continuation, but no marine shells have been detected in Hudson's Bluff, like those occasionally met with on the coast.

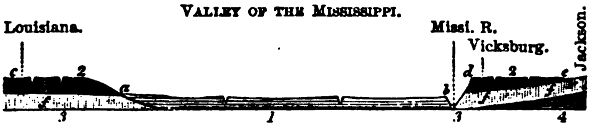
If again we ascend the river to about sixty-five miles due north of Port Hudson, or about 225 above New Orleans, we observe another bluff at Natchez, on the same left bank of the river, more than 200 feet in perpendicular height. The lower part of this cliff consists of gravel and sand, while the uppermost, sixty feet in thickness, is a mass of loam exactly resembling the loess of the valley of the Rhine, without stratification, and full of land-shells, such as Helix and Pupa, together with the amphibious genus Succinea, all of species now living in the same country. At a few points in the lower part of this formation, I observed shells of living species of Lymnea, Planorbis, and Cyclas, genera which inhabit ponds, and which may indicate the channel of an ancient river, on the borders of which, after it had shifted its course, the loess was deposited during inundations. This same loess is continuous over a vast extent of country, always increasing in thickness near the Mississippi. It occurs in a bluff at Vicksburg, eighty miles due north of Natchez (see section, fig. 42), where it forms a broad, flat table-land, extending inland about twenty-six miles from the Mississippi, or eastward from *d* to *e*. It also recurs, as I learnt from Mr. Forshey, to the west of the valley of the Mississippi, in Louisiana, or at *c*, fig. 42.

The only fossils of a truly fluviatile character which have been met with anywhere in this loess are the remains of three fish discovered lately (March 19, 1866,) by Colonel Green. They were found in the great platform of loess, two miles north of Vicksburg, and only four feet below the surface, at the height of 200 feet above high-water mark. They are

considered by Dr. Leidy to belong to the living buffalo-fish of the Mississippi, and they probably indicate some local and exceptional conditions, connected with a more rapid accumu-

FIG. 42.

VALLEY OF THE MISSISSIPPI.



1. Modern alluvium of Mississippi. 2. Loam or Loess. 3. *f*. Eocene. 4. Cretaceous.

lation than usual of mud on a part of the inundated plain on which no organic remains were usually preserved except land-shells and succineæ. I consider the loess, from its homogeneous nature, the absence of stratification, and its terrestrial and amphibious shells, to have been formed by a great river which, like the Nile, inundated the wide plains bordering it on each side. Granting this, we must assume that since its accumulation there have been great changes in the level of the basin of the Mississippi. How far the loess may have been anterior to all the formations pierced through in the well at New Orleans, or whether it may have been contemporaneous with some of them, is a point I cannot pretend to decide, especially as the Port Hudson formation bears testimony to oscillations of level at a very modern period. But it is evident that the basin of the great river has undergone important changes since the loess was deposited, although the species of land-shells contained therein are all now living. As to the mammalia, of which some bones have been found in the lowest part of the loess and in clay at its base, they are many of them of extinct species. Among these are *Mastodon giganteus*, a species of *Megalonyx*, a *Mylodon*, *Bison latifrons*, *Equus Americanus*, *Felis atrox* Leidy (a large carnivore of the size of the tiger), two species of deer, two of bear and other quadrupeds, some extinct and others still living.

Before we take leave of the great delta we may derive an instructive lesson from the reflection that the new deposits already formed, or now accumulating, whether marine or fresh-water, greatly resemble in composition, and in the general character of their organic remains, many ancient

strata which enter largely into the structure of the earth's crust. Yet there is no sudden revolution in progress, whether on the land or in the waters, whether in the animate or the inanimate world. Notwithstanding the excessive destruction of soil and uprooting of trees, the region, which yields a never-failing supply of drift-wood, is densely clothed with noble forests, and is almost unrivalled in its power of supporting animal and vegetable life. In spite of the undermining of many a lofty bluff and the encroachments of the delta on the sea—in spite of the earthquake, which rends and fissures the soil, or causes areas more than sixty miles in length to sink down several yards in a few months—the general features of the district remain unaltered, or are merely undergoing a slow and insensible change. Herds of wild deer graze on the pastures, or browse upon the trees; and if they diminish in number, it is only where they give way to man and the domestic animals which follow in his train. The bear, the wolf, the fox, the panther, and the wild cat still maintain themselves in the fastnesses of the forests of cypress and gum-tree. The racoon and the opossum are everywhere abundant, while the musk-rat, otter, and mink still frequent the rivers and lakes, and a few beavers and buffaloes have not yet been driven from their ancient haunts. The waters teem with alligators, tortoises, and fish, and their surface is covered with millions of migratory waterfowl, which perform their annual voyage between the Canadian lakes and the shores of the Mexican Gulf. The power of man, it is true, begins almost everywhere to be sensibly felt, and many parts of the wilderness to be replaced by towns, orchards, and gardens. The gilded steamboats, like moving palaces, stem the force of the current, or shoot rapidly down the descending stream through the solitudes of the forests and prairies. Already does the flourishing population of the great valley far exceed that of the thirteen United States when first they declared their independence. Such is the state of a continent where trees and stones are hurried annually, by a thousand torrents, from the mountains to the plains, and where sand and finer matter are swept down by a vast current to the sea, together with the wreck of countless forests and the bones of animals

which perish in the inundations. When these materials reach the gulf, they do not render the waters unfit for aquatic animals; but, on the contrary, the sea here swarms with life as it generally does where the influx of a great river furnishes a copious supply of organic and mineral matter. Yet some people, when they behold the spoils of the land heaped in successive strata, and blended confusedly with the remains of fishes, broken shells, and corals—when they see portions of erect trunks of trees with their roots still retaining their natural position, and one tier of them preserved above another —are apt to imagine that they are viewing the signs of a turbulent instead of a tranquil and settled state of the planet. They read in such phenomena the proof of chaotic disorder and reiterated catastrophes, instead of indications of a surface as habitable as the most delicious and fertile districts now tenanted by man.

Delta of the Amazons.—What has generally been called the delta of the Amazons forms, according to Mr. Bates,* an irregular triangle, of which each side measures about 180 miles, but the island of Marajo, which is as large as Sicily, occupies a great portion of this space, and inside of this to the west there are other smaller islands, all now, like Marajo, surrounded by different arms of the Amazons, and of the Para, the waters of which are blended in a common estuary. The valley of the Amazons has been lately examined by Professor Agassiz, who describes it as consisting of three formations, all of which he considers to be of Post-tertiary date, and to have been deposited in succession far and wide in the great basin.† The lowest is a sandstone, the next above consists of mottled plastic clays, overlaid by a series of finely laminated clays of various colours, and containing well-preserved leaves of plants supposed to belong to the existing vegetation of the country. These clays pass upwards into sands and sandstone, occasionally divided by an argillaceous layer, and at some points, as at Obydos, on the mainland nearly 300 miles westward of Marajo, calcareous beds occur with fresh-water bivalve shells of existing species. Over this

* Henry Walter Bates, Delta of the Amazons, Brit. Assoc. Report, 1864, p. 137.

† Agassiz, Physical History of Valley of Amazons, Atlantic Monthly, vol. xviii. July and August 1866.

occurs the third deposit, which appears to me, from the description given of it by Agassiz, to resemble in some parts inundation-mud or loess, and in others the produce of land-floods, which, after denuding the subjacent sandstone, have left masses of unstratified materials to level up the uneven surface of the denuded strata. The above-mentioned formations have been traced, according to Agassiz, over an area 3,000 miles in length and 700 in breadth, and their united thickness exceeds 800 feet. By the earlier observers the stratified portions of this series were supposed to be of marine origin, and were successively referred to the Devonian, Triassic, and Tertiary epochs; but Agassiz inferred that they were of modern date, and, wherever he had opportunities of examining them, of fresh-water origin. The Obydos fossils above alluded to, which former travellers ascribed to the genera Avicula, Solen, and Arca, are in reality, according to Agassiz, Unios or fresh-water bivalves of the family of Naiades, greatly resembling in shape the marine genera above mentioned, but of species now living in the Amazons. Mr. Bates informs me that Spix and Martius considered certain calcareous beds of the same formation, which occur nearer the sea and are used for making lime, to be of marine origin. These shell-beds are found at the mouth of the Tocantins, on the island of Marajo and towards the sea coast near Vigia. From the latter place Mr. Bates himself procured large marine univalves of existing species, some of them allied to Fusus.

More lately (October 1870) Professor James Orton, of a Vassor College, New York, found shells indicating fresh or brackish water life in the coloured plastic clays at Pebos, a more than 2,000 miles up the river, which he considers to be the equivalent of the mottled plastic clays of Agassiz. Mr. Conrad, to whom these shells were submitted, states that most of the forms are very singular and unique, belonging to about seventeen extinct species, referable to nine genera, of which only three are now living. From this it is inferred, says Professor Orton, that the formation cannot be late Tertiary, and may be Miocene.* The great mass of shells are bivalves

* See H. Woodward on Tertiary Shells of the Amazons Valley, Ann. and Mag. of Nat. Hist., Jan. and Feb. 1871; and Conrad, American Journ. of Conchology, Oct. 10, 1870.

of Conrad's new genus *Anysothyris* (*Pachydon Gabb*), now represented in the estuary of the La Plata by *Potomomya* (*Azara*) *labiata*. Assuming that the seventeen species are all extinct, this would imply that this fossil fauna recedes more from that now living than does any known member even of the Lower Miocene of Europe.

That we should be unable to form even a probable guess as to the geological and geographical relations of these deposits, in a country which has only been surveyed in what must be called a rapid and hurried visit during a single season, is not wonderful. Suppose, for example, that a scientific expedition had explored for the first time the valley of the Rhine. On entering the Scheldt they would find at Antwerp Pliocene strata, in some of which the great majority of shells agree with those now living in the neighbouring sea. Pursuing their course up the river for 200 or 300 miles, they would behold on both sides of the valley of the Rhine, as between Bingen and Basle, a mass of loess, with recent land and amphibious shells, from 100 to 200 feet thick, having sometimes, but rarely, at the bottom, fresh-water deposits, with living species of Lymnea, Planorbis, and Paludina comparable in age to those of Obydos; while at Bonn, Mayence, and other places they would find Tertiary strata containing at various heights fresh-water, brackish, and marine fossils, for the most part of extinct species and Miocene date. In the report of such a supposed expedition made for the first time it would be unreasonable to expect that the successive changes in organic life or physical geography of the Tertiary and recent formations of the Rhenish basin should be clearly determined, seeing that after the study of more than half a century we have not yet accomplished this end. Yet the basin of the Rhine is only a fourth part the size of that of the Amazons.

In order to explain the great Amazonian formation above described, Professor Agassiz conceives that the whole valley was for a long period converted into a lake, by a large dam or barrier stretching across its seaward extremity, and which has since been removed by the ocean. A similar hypothesis has been advanced again and again to account for the vast extent of old fluviatile and lacustrine deposits, as well as

for the inundation-mud called loess, which once filled the lower portions of the basins of most of the principal rivers of the world, such as the Mississippi, Nile, Danube, and Rhine. I have elsewhere* endeavoured to show that such phenomena are the natural result of oscillations in the level of the land, extending over large continental areas, by which the fall of the rivers is lessened at certain periods, giving rise to accumulations of matter more or less lacustrine, while subsequently, when a movement takes place in an opposite direction, the rivers cut through their old deposits, re-excavating the valleys and often eroding them below their original depth. There is nothing new therefore in the character of the Amazonian clays, sands, and loess, so far at least as they are of recent and post-Tertiary date, except the grand scale on which they are developed. Geologists have usually been driven to abandon the theory of a seaward dam at the mouths of great rivers, such as the Rhine and Mississippi, by the difficulty of imagining first the construction of such barriers after the valley was formed, and then their subsequent disappearance.

Professor Agassiz has hazarded the startling conjecture that the Amazonian basin was closed up and converted into a lake by the terminal moraine of a glacier, which stretched for thousands of miles from west to east, and entered the sea under the equator. But this distinguished naturalist candidly confesses that he failed to discover any of those proofs which we are accustomed to regard, even in temperate latitudes, as essential for the establishment of the former existence of glaciers where they are now no more. No glaciated pebbles, or far-transported angular blocks, with polished and striated sides, no extensive surface of rock, smooth and traversed by rectilinear furrows, were observed.

The islands, such as Marajo and others, off the present mouth of the Amazons, certainly imply that vast encroachments of the ocean have taken place since the clays and sands above described were formed. We are also informed by Agassiz that even in the last ten years the sea has gained upon the land on one part of the coast as much as 200 yards,

* See above, p. 301, and Ant. of Man, p. 333; Elements of Geology, p. 118.

and within the last twenty years one island north-east of the Bay of Vigia has been entirely swept away, while it is probable that the Paranahyba and some other rivers in the province of Maranham, which now enter the ocean by independent mouths, were once tributaries of the Amazons. From Mr. Bates we learn that about 140 miles inland from the present coast-line, is a low flat area about 80 miles in length and width, wholly formed of mud and sediment in comparatively recent times, by the Amazons. The same traveller gives us a graphic account of the rate at which the great river in the higher parts of its course is denuding its banks. 'One morning,' he says, 'I was awoke before sunrise by an unusual sound resembling the roar of artillery; the noise came from a considerable distance, one crash succeeding another. I supposed it to be an earthquake, for, although the night was breathlessly calm, the broad river was much agitated, and the vessel rolled heavily. Soon after another loud explosion took place, followed by others, which lasted for an hour till the day dawned, and we then saw the work of destruction going forward on the other side of the river, about three miles off. Large masses of forest, including trees of colossal size, probably 200 feet in height, were rocking to and fro, and falling headlong one after another into the water. After each avalanche, the wave which it caused returned on the crumbly bank with tremendous force, and caused the fall of other masses by undermining. The line of coast over which the landslip extended was a mile or two in length; the end of it, however, was hid from our view by an intervening island. It was a grand sight; each downfall created a cloud of spray; the concussion in one place causing other masses to give way a long distance from it, and thus the crashes continued, swaying to and fro with little prospect of a termination. When we glided out of sight two hours after sunrise the destruction was still going on.' *

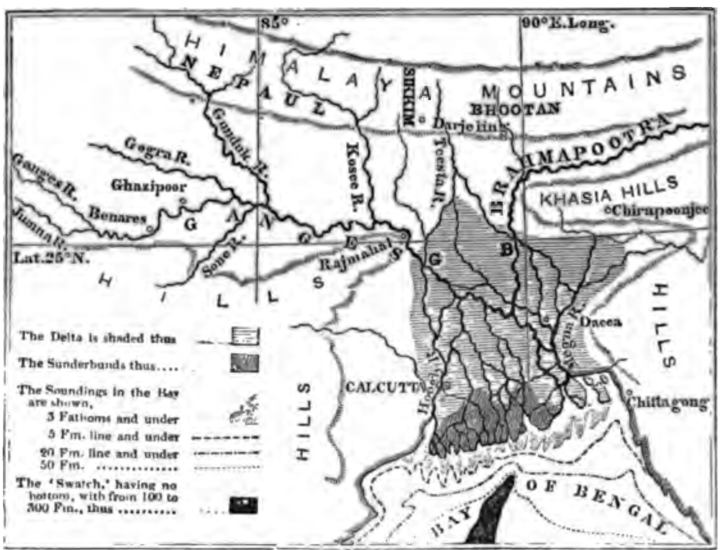
DELTA OF THE GANGES AND BRAHMAPOOTRA.

As an example of a large delta advancing upon the sea in spite of the action of a very powerful tide, I shall next

* Bates, Naturalist on the Amazons, vol. ii. p. 172. 1863.

describe that of the Ganges and Brahmapootra (or Burrampooter). These, the two principal rivers of India, descend from the highest mountains in the world, and partially mingle their waters in the low plains of Hindoostan, before reaching the head of the Bay of Bengal. The Brahmapootra, somewhat the larger of the two, formerly passed to the east of Dacca, even so lately as the beginning of the present century, pouring most of its waters into one of the numerous channels in the Delta called 'the Megna.' By that name the main stream was always spoken of by Rennell and others in their

Fig. 42.



MAP of the DELTA of the GANGES and BRAHMAPOOTRA.

memoirs on this region. But the main trunk now unites with an arm of the Ganges considerably higher up, at a point about 100 miles distant from the sea; and it is constantly, according to Dr. Hooker, working its way westward, having formerly, as may be seen by ancient maps, moved eastward for a long period.

The area of the delta of the combined rivers, for it is impossible now to distinguish what belongs to each, is considerably more than double that of the Nile, even if we exclude

from the delta a large extent of low, flat, alluvial plain, doubtless of fluviatile origin, which stretches more than 100 miles to the hills west of Calcutta (see map, fig. 43), and much farther in a northerly direction beyond the head of the great delta. The head of a delta, as before stated, is that point where the first arm is given off. Above that point a river receives the waters of tributaries flowing from higher levels; below it, on the contrary, it gives out portions of its waters to lower levels through channels which flow into adjoining swamps, or which run directly to the sea. In the great delta of Bengal there may be said to be two heads nearly equi-distant from the sea, that of the Ganges (G, map, fig. 43), about thirty miles below Rajmahal, or 216 statute miles in a direct line from the sea, and that of the Brahmapootra (B) below Chirapoonjee, where the river issues from the Khasia mountains, a distance of 224 miles from the Bay of Bengal.

It will appear, by reference to the map, that the great body of fresh water derived from the two rivers enters the bay on its eastern side; and that a large part of the delta bordering on the sea is composed of a labyrinth of rivers and creeks, all filled with salt water, except those immediately communicating with the Hoogly, or principal arm of the Ganges. This tract alone, known by the name of the Woods, or Sunderbunds (more properly Soonderbuns), a wilderness infested by tigers and crocodiles, is, according to Rennell, equal in extent to the whole principality of Wales.*

On the sea-coast there are eight great openings, each of which has evidently, at some ancient period, served in its turn as the principal channel of discharge. Although the flux and reflux of the tide extend even to the heads of the delta when the rivers are low, yet, when they are periodically swollen by tropical rains, their volume and velocity counteract the tidal current, so that, except very near the sea, the ebb and flow become insensible. During the flood season, therefore, the Ganges and Brahmapootra almost assume in their delta the character of rivers entering an inland sea; the movements of the ocean being then subordinate to the

* Account of the Ganges and Burrampooter Rivers, by Major Rennell, Phil. Trans. 1718.

force of the rivers, and only slightly disturbing their operations. The great gain of the delta in height and area takes place during the inundations; and, during other seasons of the year, the ocean makes reprisals, scouring out the channels, and sometimes devouring rich alluvial plains.

Islands formed and destroyed.—Major R. H. Colebrooke, in his account of the course of the Ganges, relates examples of the rapid filling up of some of its branches, and the excavation of new channels where the number of square miles of soil removed in a short time (the column of earth being 114 feet high) was truly astonishing. Forty square miles, or 25,600 acres, are mentioned as having been carried away, in one place, in the course of a few years.* The immense transportation of earthy matter by the Ganges and Brahmapootra is proved by the great magnitude of the islands formed in their channels during a period far short of that of a man's life. Some of these, many miles in extent, have originated in large sand-banks thrown up round the points at the angular turning of the rivers, and afterwards insulated by breaches of the streams. Others, formed in the main channel, are caused by some obstruction at the bottom. A large tree, or a sunken boat, is sometimes sufficient to check the current and cause a deposit of sand, which accumulates till it usurps a considerable portion of the channel. The river then undermines its banks on each side, to supply the deficiency in its bed, and the island is afterwards raised by fresh deposits during every flood. In the great gulf below Luckipour, formed by the united waters of the Ganges and Megna, some of the islands, says Rennell, rival in size and fertility the Isle of Wight. While the river is forming new islands in one part, it is sweeping away old ones in others. Those newly formed are soon overrun with reeds, long grass, the Tamarix Indica, and other shrubs, forming impenetrable thickets, where the tiger, the rhinoceros, the buffalo, deer, and other wild animals, take shelter. It is easy, therefore, to perceive, that both animal and vegetable remains may occasionally be precipitated into the flood, and become imbedded in the sediment which subsides in the delta.

* Trans. of the Asiatic Society, vol. vii. p. 14.

Three or four species of crocodile, of two distinct sub-genera, abound in the Ganges, and its tributary and contiguous waters; and Mr. H. T. Colebrooke informed me, that he had seen both forms in places far inland, several hundred miles from the sea. The Gangetic crocodile, or Gavial (in correct orthography, Garial), is confined to the fresh water, living exclusively on fish, but the commoner kinds, called Koomiah and Muggar, frequent both fresh and salt, being much larger and fiercer in salt and brackish water.* These animals swarm in the brackish water along the line of sand-banks, where the advance of the delta is most rapid. Hundreds of them are seen together in the creeks of the delta, or basking in the sun on the shoals without. They will attack men and cattle, destroying the natives when bathing, and tame and wild animals which come to drink. 'I have not unfrequently,' says Mr. Colebrooke, 'been witness to the horrid spectacle of a floating corpse seized by a crocodile with such avidity, that he half emerged above the water with his prey in his mouth.' The geologist will not fail to observe how peculiarly the habits and distribution of these saurians expose them to become imbedded in the horizontal strata of fine mud which are annually deposited over many hundred square miles in the Bay of Bengal. The inhabitants of the land who happen to be drowned or thrown into the water are usually devoured by these voracious reptiles; but we may suppose the remains of the saurians themselves to be continually entombed in the new formations. The number, also, of bodies of the poorer class of Hindoos thrown annually into the Ganges is so great, that some of their bones or skeletons can hardly fail to be occasionally enveloped in fluviatile mud.

It sometimes happens, at the season when the periodical flood is at its height, that a strong gale of wind, conspiring with a high spring-tide, checks the descending current of the

* Cuvier referred the true crocodiles of the Ganges to a single species, *C. biporcatus*. But I learn from Dr. Falconer that there are three well-marked species, *C. biporcatus*, *C. palustris*, and *C. bombifrons*. *C. bombifrons* occurs in the northern branches of the Ganges, 1,000 miles from Calcutta; *C. biporcatus* appears to be confined to the estuary and *C. palustris*, to range from the estuary to the central parts of Bengal. The Garial (*C. palustris*) is found along with *C. bombifrons* in the north, and descends to the region of *C. biporcatus* in the estuary.

river, and gives rise to most destructive inundations. From this cause, in the year 1763, the waters at Luckipour rose six feet above their ordinary level, and the inhabitants of a considerable district, with their houses and cattle, were totally swept away.

The population of all oceanic deltas are particularly exposed to suffer by such catastrophes, recurring at considerable intervals of time; and we may safely assume that such tragical events have happened again and again, since the Gangetic delta was inhabited by man. If human experience and forethought cannot always guard against these calamities, still less can the inferior animals avoid them; and the monuments of such disastrous inundations must be looked for in great abundance in strata of all ages, if the surface of our planet has always been governed by the same laws. When we reflect on the general order and tranquillity that reign in the rich and populous delta of Bengal, notwithstanding the havoc occasionally committed by the depredations of the ocean, we perceive how unnecessary it is to attribute the imbedding of successive races of animals in older strata to extraordinary energy in the causes of decay and reproduction in the infancy of our planet, or to those general catastrophes and sudden revolutions so often resorted to.

Deposits in the delta.—The quantity of mud held in suspension by the waters of the Ganges and Brahmapootra is found, as might be expected, to exceed that of any of the rivers alluded to in this or the preceding chapters; for, in the first place, their feeders flow from mountains of unrivalled altitude, and do not clear themselves in any lake, as does the Rhine in the Lake of Constance, or the Rhone in that of Geneva. And, secondly, their whole course is nearer the equator than that of the Mississippi, or any great river respecting which careful experiments have been made, to determine the quantity of its water and earthy contents. The fall of rain, moreover, as we have before seen, is excessive on the southern flanks of the first range of mountains which rise from the plains of Hindoostan, and still more remarkable is the quantity sometimes poured down in one day. (See above, p. 324.) The sea, where the Ganges and Brahmapootra

discharge their main stream at the flood season, only recovers its transparency at the distance of from 60 to 100 miles from the delta; and we may take for granted that the current continues to transport the finer particles much farther south than where the surface water first becomes clear. The general slope, therefore, of the new strata must be extremely gentle. According to the best charts, there is a gradual deepening from four to about sixty fathoms, as we proceed from the base of the delta to the distance of about one hundred miles into the Bay of Bengal. At some few points seventy, or even one hundred, fathoms are obtained at that distance.

One remarkable exception, however, occurs to the regularity of the shape of the bottom. Opposite the middle of the delta, at the distance of thirty or forty miles from the coast, there is a deep submarine valley, called the 'swatch of no ground,' about fifteen miles in breadth, where soundings varying from 180 to 300 fathoms fail to reach the bottom. (See map, p. 468.) This phenomenon is the more extraordinary, since the depression runs north to within five miles of the line of shoals; and not only do the waters charged with sediment pass over it continually, but, during the monsoons, the sea, loaded with mud and sand, is beaten back in that direction towards the delta. As the mud is known to extend for eighty miles farther into the gulf, a considerable thickness of matter must have been deposited in 'the swatch.' We may conclude, therefore, either that the original depth of this part of the Bay of Bengal was excessive, or that subsidences have occurred in modern times. The latter conjecture is the less improbable, as the delta near Calcutta has certainly been sinking (as shown by Artesian borings, see p. 476) during the period of its formation. Parts of Bengal have also been convulsed in the historical era by earthquakes, and actual subsidences have taken place in the neighbouring coast of Chittagong, while 'the swatch' lies not far from the volcanic band which connects Sumatra, Barren Island, and Ramree.*

Mr. Fergusson has suggested that 'the swatch,' in which

* See below, Chaps. XXIII. and XXX.

soundings have been made to the depth of no less than 1,800 feet without reaching the bottom, is a channel 'scooped out' by the force of the tides, or one which they have had power to keep clear. In support of this view he observes that the tides of the Hoogly have a rotatory motion;* but he is unable to confirm this by any exact observations as to their velocity, such as might warrant us in ascribing so extraordinary an effect to their excavating power. To me it seems less difficult to conceive the pre-existence of a submarine valley 2,000 feet or more deep, which may have formed part of the original basin of the Bay of Bengal. Before the two great rivers the Ganges and Brahmapootra reach this deep and central part of the gulf they meet the tidal current, and, their speed being checked, they part with their sediment, which has in this way been prevented from filling up 'the swatch.'

Opposite the mouth of the Hoogly River, and immediately south of Saugor Island, four miles from the nearest land of the delta, a new islet was formed at the beginning of the present century, called Edmonstone Island, on the centre of which a beacon was erected as a landmark in 1817. In 1818 the island had become two miles long and half a mile broad, and was covered with vegetation and shrubs. Some houses were then built upon it, and in 1820 it was used as a pilot station. The severe gale of 1823 divided it into two parts and so reduced its size as to leave the beacon standing out in the sea, where, after remaining seven years, it was washed away. The islet in 1836 had been converted by successive storms into a sand-bank, half a mile long, on which a sea-mark was placed.

Although there is evidence of gain at some points, the general progress of the coast is very slow; for the tides, when the river water is low, are actively employed in removing alluvial matter. In the Sunderbunds the usual rise and fall of the tides is no more than eight feet, but, on the east side of the delta, Dr. Hooker observed, in the winter of 1851, a rise of from sixty to eighty feet, producing among the islands at the mouths of the Megna and Fenny Rivers a lofty

* Fergusson, Changes in Delta of the Ganges, Quart. Geol. Journ. vol xix. 1863.

wave or 'bore' as they ascend, and causing the river water to be ponded back, and then to sweep down with great violence when the tide ebbs. The bay for forty miles south of Chittagong is so fresh that neither algæ nor mangroves will grow on it. We may, therefore, conceive how effective may be the current formed by so great a volume of water in dispersing fine mud over a wide area. Its power is sometimes augmented by the agitation of the bay during hurricanes in the month of May. The new superficial strata consist entirely of fine sand and mud; such, at least, are the only materials which are exposed to view in regular beds on the banks of the numerous creeks. Neither here nor higher up the Ganges could Dr. Hooker discover any land or fresh-water shells in sections of the banks, which in the plains higher up sometimes form cliffs eighty feet in height at low water. In like manner I have elsewhere stated* that I was unable to find any buried shells in the delta or modern river cliffs of the Mississippi.

The Ganges is always raising the level of its bed and banks in the same manner as the Mississippi, before described (p. 439, diagram, fig. 37); and we learn from Sir Proby Cautley and Colonel Baker, that even artificial canals constructed for inland navigation in India, such as those of the Jumna, through which the water flows freely, deposit in like manner much of the coarser matter immediately on their banks, so that these last form a miniature representation of those of larger rivers. Mr. J. Fergusson, in his paper on the Delta of the Ganges,† differing from all writers of authority who preceded him, has argued that the sediment is thrown down in consequence of the overflowing river being checked by meeting with the still water of the jheels or lakes corresponding to those seen at *g f* and *d e*, fig. 37, p. 439. In point of fact, however, the deposition of the coarser matter takes place immediately on the highest part of the banks, where the waters first begin to overflow, and before they reach those lakes which occur at a lower level in the alluvial plain on each side of the main river. The banks are of equal height and as continuous where no jheels exist.

* Second Visit to United States, vol. ii. p. 145. † Fergusson, ibid.

No substance so coarse as gravel occurs in any part of the delta of the Ganges and Brahmapootra, nor nearer the sea than 400 miles. Yet it is remarkable that the boring of an Artesian well at Fort William, near Calcutta, in the years 1835–1840, displayed at the depth of 120 feet, clay and sand with pebbles. This boring was carried to a depth of 481 feet below the level of Calcutta, and the geological section obtained in the operation has been recorded with great care. Under the surface soil, at a depth of about ten feet, they came to a stiff blue clay about forty feet in thickness; below which was sandy clay, containing in its lower portion abundance of decayed vegetable matter, which at the bottom assumed the character of a stratum of black peat two feet thick. This peaty mass was considered as a clear indication (like the 'dirt-bed' of Portland) of an ancient terrestrial surface, with a forest or Sunderbund vegetation. Logs and branches of a red-coloured wood occur both above and immediately below the peat, so little altered that Dr. Wallich was able to identify them with the Soondri tree, *Heritiera littoralis*, one of the most prevalent forms at the base of the delta. Dr. Falconer tells me that similar peat has been met with at other points round Calcutta at the depth of nine feet and twenty-five feet. It appears, therefore, that there has been a sinking down of what was originally land in this region, to the amount of seventy feet or more; for Calcutta is only a few feet above the level of the sea, and the successive peat-beds seem to imply that the subsidence of the ground was gradual or interrupted by several pauses. Continuing the boring at Fort William, they entered, below the vegetable mass, upon a stratum of yellowish clay about ten feet thick, containing horizontal layers of kunkar (or kankar), a nodular, concretionary, argillaceous limestone, met with abundantly at greater or less depths in all parts of the valley of the Ganges, over many thousand square miles, and always presenting the same characters, even at a distance of one thousand miles north of Calcutta. Some of this kunkar is said to be of very recent origin in deposits formed by river inundations near Saharanpoor. After penetrating 120 feet, they found loam

containing water-worn fragments of mica-slate and other kinds of rock, of a size which the current of the Ganges can no longer transport to this region. In the various beds pierced through below, consisting of clay, marl, and friable sandstone, with kunkar here and there intermixed, no organic remains of decidedly marine origin were met with. Too positive a conclusion ought not, it is true, to be drawn from such a fact, when we consider the narrow bore of the auger and its effect in crushing shells and bones. Nevertheless, it is worthy of remark, that the only fossils obtained in a recognisable state were of a fluviatile or terrestrial character. Thus, at the depth of 350 feet, the bony shell of a tortoise, or trionyx, a fresh-water genus resembling the living species of Bengal, was found in sand. From the same stratum, also, they drew up the lower half of the humerus of a ruminant, of the size and shape, says Dr. Falconer, of the shoulder-bone of the *Cervus porcinus*, or common hog-deer, of India. At the depth of 380 feet, clay with fragments of lacustrine shells was incumbent on what appears clearly to have been another 'dirt-bed,' or stratum of decayed wood, implying a period of repose of some duration, and a forest-covered land, which must have subsided 300 feet, to admit of the subsequent superposition of the overlying deposits. It has been conjectured that, at the time when this area supported trees, the land extended much farther out into the Bay of Bengal than now, and that in latter times the Ganges, while enlarging its delta, has been only recovering lost ground from the sea.

At the depth of about 400 feet below the surface, an abrupt change was observed in the character of the strata, which were composed in great part of sand, shingle, and boulders, the only fossils observed being the vertebræ of a crocodile, shell of a trionyx, and fragments of wood very little altered and similar to that buried in beds far above. These gravelly beds constituted the bottom of the section at the depth of 481 feet, when the operations were discontinued in consequence of an accident which happened to the auger.

The occurrence of pebbles at the depths of 120 and 400 feet

implies important changes in the geographical condition of the region round or near Calcutta. The fall of the river, or the general slope of the alluvial plain, may have been formerly greater; or, before a general and perhaps unequal subsidence, hills once nearer the present base of the delta may have risen several hundred feet, forming islands in the bay, which may have sunk gradually, and become buried under fluviatile sendiment.

Antiquity of the delta.—It would be a matter of no small scientific interest, if experiments were made to enable us to determine, with some degree of accuracy, the mean quantity of earthy matter discharged annually into the sea by the united waters of the Ganges and Brahmapootra. The Rev. Mr. Everest instituted, in 1831–2, a series of observations on the earthy matter brought down by the Ganges, at Ghazepoor, 500 miles from the sea. He found that, in 1831, the number of cubic feet of water discharged by the river per second at that place was during the

Rains (4 months)	494,208
Winter (5 months)	71,200
Hot weather (3 months) . . .	36,330

so that we may state in round numbers that 500,000 cubic feet per second flow down during the four months of the flood season, from June to September, and about 100,000 per second during the remaining eight months.

The average quantity of solid matter suspended in the water during the rains was, by weight, $\frac{1}{428}$th part; but as the water is about one half the specific gravity of the dried mud, the solid matter discharged is $\frac{1}{856}$th part in bulk, or 577 cubic feet per second. This gives a total of 6,082,041,600 cubic feet for the discharge in the 122 days of the rain. The proportion of sediment in the waters at other seasons was comparatively insignificant, the total amount during the five winter months being only 247,881,600 cubic feet, and during the three months of hot weather, 38,154,240 cubic feet. The total annual discharge, then, would be 6,368,077,440 cubic feet.

This quantity of mud would in one year raise a surface of 228½ square miles, or a square space, each side of which should measure 15 miles, a height of one foot. To give some idea of the magnitude of this result, we will assume that the specific gravity of the dried mud is only one half that of granite (it would, however, be more): in that case, the earthy matter discharged in a year would equal 3,184,038,720 cubic feet of granite. Now about 12½ cubic feet of granite weigh one ton; and it is computed that the Great Pyramid of Egypt, if it were a solid mass of granite, would weigh about 6,000,000 tons. The mass of matter, therefore, carried down annually would, according to this estimate, more than equal in weight and bulk forty-two of the great pyramids of Egypt, and that borne down in the four months of the rains would equal forty pyramids. But if, without any conjecture as to what may have been the specific gravity of the mud, we attend merely to the weight of solid matter actually proved by Mr. Everest to have been contained in the water, we find that the number of tons' weight which passed down in the 122 days of the rainy season was 339,413,760, which would give the weight of fifty-six pyramids and a half; and in the whole year 355,361,464 tons, or nearly the weight of sixty pyramids.

The base of the Great Pyramid of Egypt covers eleven acres, and its perpendicular height is about five hundred feet. It is scarcely possible to present any picture to the mind which will convey an adequate conception of the mighty scale of this operation, so tranquilly and almost insensibly carried on by the Ganges, as it glides through its alluvial plain, even at a distance of 500 miles from the sea. It may, however, be stated, that if a fleet of more than eighty Indiamen, each freighted with about 1,400 tons' weight of mud, were to sail down the river every hour of every day and night for four months continuously, they would only transport from the higher country to the sea a mass of solid matter equal to that borne down by the Ganges, even in this part of its course, in the four months of the flood season. Or the exertions of a fleet of about 2,000 such ships going down daily with the same burden, and discharging it into the gulf, would

be no more than equivalent to the operations of the great river.

The most voluminous current of lava which has flowed from Etna within historical times was that of 1669. Ferrara, after correcting Borelli's estimate, calculated the quantity of cubic yards of lava in this current at 140,000,000. Now this would not equal in bulk one-fifth of the sedimentary matter which is carried down in a single year by the Ganges, past Ghazepoor, according to the estimate above explained; so that it would require five grand eruptions of Etna to transfer a mass of lava from the subterranean regions to the surface, equal in volume to the mud carried down in one year to Ghazepoor.

Colonel R. Strachey, of the Bengal Engineers, has remarked to me, not only that Ghazepoor, where Mr. Everest's observations were made, is 500 miles from the sea, but that the Ganges has not been joined there by its most important feeders. These drain upon the whole 750 miles of the Himalaya, and no more than 150 miles of that mountain-chain have sent their contributions to the main trunk at Ghazepoor. Below that place, the Ganges is joined by the Gogra, Gunduk, Khosee, and Teesta from the north, to say nothing of the Sone flowing from the south, one of the largest of the rivers which rise in the table-land of central India. (See map, fig. 43, p. 468.) Moreover, the remaining 600 miles of the Himalaya comprise that eastern portion of the basin where the rains are heaviest. (See above, p. 324.) The quantity of water therefore carried down to the sea may probably be four or five times as much as that which passes Ghazepoor.

The Brahmapootra, according to Major Wilcox,* in the month of January, when it is near its minimum, discharges 150,000 cubic feet of water per second at Gwalpara, not many miles above the head of its delta. Taking the proportions observed at Ghazepoor at the different seasons as a guide, the probable average discharge of the Brahmapootra for the whole year may be estimated at about the same as that of the Ganges. Assuming this; and secondly,

* Asiatic Researches, vol. xvii. p. 466.

in order to avoid the risk of exaggeration, that the proportion of sediment in their waters is about a third less than Mr. Everest's estimate, the mud borne down to the Bay of Bengal in one year would equal 40,000 millions of cubic feet, or between six and seven times as much as that brought down to Ghazepoor, according to Mr. Everest's calculations in 1831, and five times as much as that conveyed annually by the Mississippi to the Gulf of Mexico.

Colonel Strachey estimates the annually inundated portion of the delta at 250 miles in length by 80 in breadth, making an area of 20,000 square miles. The space south of this in the bay, where sediment is thrown down, may be 300 miles from E. to W. by 150 N. and S., or 45,000 square miles, which, added to the former, gives a surface of 65,000 square miles, over which the sediment is spread out by the two rivers. Suppose then the solid matter to amount to 400,000 millions of cubic feet per annum, the deposit, he observes, must be continued for forty-five years and three-tenths to raise the whole area a height of one foot, or 13,600 years to raise it 300 feet; and this, as we have seen, is much less than the thickness of the fluviatile strata actually penetrated (and the bottom not reached) by the auger at Calcutta.

Nevertheless we can by no means deduce from these data alone, what will be the future rate of advance of the delta, nor even predict whether the land will gain on the sea, or remain stationary. At the end of 13,000 years the bay may be even less shallow than now, provided a moderate depression, corresponding to that experienced in part of Greenland for many centuries shall take place (see p. 128). A subsidence quite insensible to the inhabitants of Bengal, not exceeding two feet three inches in a century, would be more than sufficient to counterbalance all the efforts of the two mighty rivers to extend the limits of their delta. We have seen that the Artesian borings at Calcutta attest, what the vast depth of the 'swatch' may also perhaps indicate, that the antagonist force of subsidence has predominated for ages over the influx of fluviatile mud, preventing it from raising the plains of Bengal, which now at Calcutta are only a few

inches above the level, or from filling up a larger portion of the bay.

CONCLUDING REMARKS ON DELTAS.

Convergence of deltas.—If we possessed an accurate series of maps of the Adriatic for many thousand years, our retrospect would, without doubt, carry us gradually back to the time when the number of rivers descending from the mountains into that gulf by independent deltas was far greater. The deltas of the Po and the Adige, for instance, would separate themselves within the Post-tertiary era, as, in all probability, would those of the Isonzo and the Torre. If, on the other hand, we speculate on future changes, we may anticipate the period when the number of deltas will greatly diminish; for the Po cannot continue to encroach at the rate of a mile in a hundred years, and other rivers to gain as much in six or seven centuries upon the shallow gulf, without new junctions occurring from time to time; so that Eridanus, 'the king of rivers,' will continually boast a greater number of tributaries. The Ganges and the Brahmapootra have perhaps become partially confluent in the same delta within the historical, or at least within the human, era; and the date of the junction of the Red River and the Mississippi would, in all likelihood, have been known, if America had not been so recently discovered. The union of the Tigris and the Euphrates must undoubtedly have been one of the modern geographical changes of our earth, for Sir Henry Rawlinson informs me (1853) that the delta of those rivers has advanced two miles in the last sixty years, and is supposed to have encroached about forty miles upon the Gulf of Persia in the course of the last twenty-five centuries.

When the deltas of rivers, having many mouths, converge, a partial union at first takes place by the confluence of some one or more of their arms; but it is not until the main trunks are connected above the head of the common delta, that a complete intermixture of their joint waters and sediment takes place. The union, therefore, of the Po and Adige, and of the Ganges and Brahmapootra, is still incom-

plete. If we reflect on the geographical extent of surface drained by rivers such as now enter the Bay of Bengal, and then consider how complete the blending together of the greater part of their transported matter has already become, and throughout how vast a delta it is spread by numerous arms, we no longer feel so much surprise at the area occupied by some ancient formations of homogeneous mineral composition. But our surprise will be still farther lessened when we afterwards enquire (Ch. XXII.) into the action of tides and currents in disseminating sediment.

Age of existing deltas.—If we could take for granted, that the relative level of land and sea had remained stationary ever since all the existing deltas began to be formed—could we assume that their growth commenced at one and the same instant when the present continents acquired their actual shape—we might understand the language of geologists who speak of 'the epoch of existing continents.' They endeavour to calculate the age of deltas from this imaginary fixed period; and they calculate the gain of new land upon the sea, at the mouth of rivers, as having begun everywhere simultaneously. But the more we study the history of deltas the more we become convinced that upward and downward movements of the land and contiguous bed of the sea have exerted, and continue to exert, an influence on the physical geography of many hydrographical basins, on a scale comparable in magnitude or importance to the amount of fluviatile deposition effected in an equal lapse of time. In the basin of the Mississippi, for example, proofs both of descending and ascending movements to a vertical amount of several hundred feet, can be shown to have taken place since the existing species of land and fresh-water shells lived in that region.*

The deltas also of the Po and Ganges have each, as we have seen (pp. 422 and 476), when probed by the Artesian auger, borne testimony to a gradual subsidence of land to the extent of several hundred feet—old terrestrial surfaces or 'dirt-beds,' turf, peat, forest-land, having being pierced at various depths.

* Lyell's Second Visit to the United States, vol. ii. chap. 34.

The changes of level at the mouth of the Indus in Cutch (see below, Ch. XXVIII.), and those of New Madrid in the valley of the Mississippi (see p. 453 and Ch. XXVIII.), are equally instructive, as demonstrating unceasing fluctuations in the levels of those areas into which running water is transporting sediment. If, therefore, the exact age of all modern deltas could be known, it is scarcely probable that we should find any two of them in the world to have coincided in date, or in the time when their earliest deposits originated.

Grouping of strata in deltas.—The changes which have taken place in deltas, even within the times of history, may suggest many important considerations in regard to the manner in which subaqueous sediment is distributed. If a lake, for example, be encircled on two sides by lofty mountains, receiving from them many rivers and torrents of different sizes, and if it is bounded on the other sides, where the surplus waters issue, by a comparatively low country, it is not difficult to define some of the leading geological features which must characterise the lacustrine formation, when this basin shall have been gradually converted into dry land by the influx of sediment.

The detritus washed down by rivers and torrents from the adjoining height to the edge of the lake would sink at once into deep water, all the heavier pebbles and sand subsiding near the shore. The finer mud would be carried somewhat farther out, but not to the distance of many miles, for the greater part, as is seen where the Rhone enters the Lake of Geneva, falls down in clouds to the bottom, not far from the river's mouth. Thus alluvial tracts are formed near the shore at the mouths of every torrent and river; pebbles and sand are then transported farther from the mountains; but in their passage they decrease in size by attrition, and are in part converted into mud and sand. At length some of the numerous deltas, which are all directed towards a common centre, approach near to each other; those of adjoining torrents become united, and each is merged, in its turn, in the delta of the largest river, which advances most rapidly into the lake, and renders all the minor streams, one after the other, its tributaries. The various

mineral ingredients of all are thus blended together into one homogeneous mixture, and the sediment is poured out from a common channel into the lake.

As the average size of the transported particles decreases, while the force and volume of the main river augments, the newer deposits are diffused continually over a wider area, and are consequently more horizontal than the older. When at first there were many independent deltas near the borders of the basin, their separate deposits differed entirely from each other; one may have been charged, like the Arve where it joins the Rhone, with white sand and sediment derived from granite—another may have been black, like many streams in the Tyrol, flowing from the waste of decomposing rocks of dark slate—a third may have been coloured by ochreous sediment, like the Red River in Louisiana—a fourth, like the Elsa in Tuscany, may have held much carbonate of lime in solution. At first they would each form distinct deposits of sand, gravel, limestone, marl, or other materials; but after their junction, new chemical combinations and a distinct colour would be the result, and the particles, having been conveyed ten, twenty, or a greater number of miles over alluvial plains, would become finer. The more ancient system of strata would be composed for the most part of coarser materials, and would sometimes dip at a considerable angle, especially if consisting of beds of pebbles. The beds in the newer group would, on the whole, be finer-grained, and more homogeneous in colour and mineral composition, throughout large areas. But, although the law of arrangement here alluded to would cause the older or more littoral to be characterised in great part by coarser materials than the newer group, this latter, as it is advanced to a great distance from the shore, would be thrown down, not immediately on older rocks, but on strata made up of the finest mud which had been carried out to great distances when the littoral deltas first began to form. For this reason some of the newer strata of sand or coarser materials are often found to overlie an older set of much finer grain. By reflecting on these facts, we see that the law of arrangement must be very complex, more especially the relation between the relative

age of the different groups of sediment and the fineness of their component materials.

In those deltas where the tides and strong marine currents interfere, the above description would only be applicable with certain modifications. If a series of earthquakes accompany the growth of a delta, and change the levels of the land from time to time, as in the region where the Indus now enters the sea, the phenomena will depart still more widely from the ordinary type. If, after a protracted period of rest, a delta sink down, pebbles may be borne along in shallow water near the foot of the boundary hills, so as to form conglomerates overlying the fine mud previously thrown into deeper water in the same area.

Causes of stratification in deltas.—The stratified arrangement, which is observed to prevail so generally in aqueous deposits, is most frequently due to variations in the velocity of running water, which cannot sweep along particles of more than a certain size and weight when moving at a given rate. Hence, as the force of the stream augments or decreases, the materials thrown down in successive layers at particular places are rudely sorted, according to their dimensions, form, and specific gravity. Where this cause has not operated, as where sand, mud, and fragments of rock are conveyed by a glacier, a confused heap of rubbish devoid of all stratification is produced.

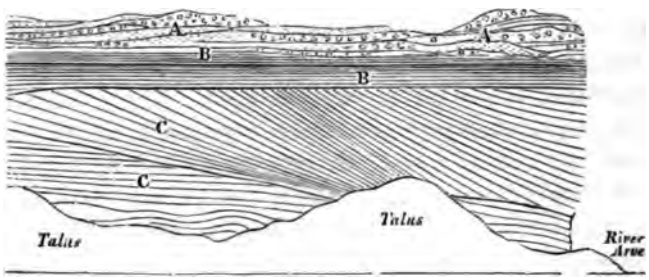
Natural divisions are also occasioned in deltas, by the interval of time which separates annually the deposition of matter during the periodical rains, or melting of the snow upon the mountains. The deposit of each year may acquire some degree of consistency before that of the succeeding year is superimposed. A variety of circumstances also gives rise annually, or sometimes from day to day, to slight variations in colour, fineness of the particles, and other characters, by which alternations of strata distinct in texture and mineral ingredients must be produced. Thus, for example, at one period of the year, drift wood may be carried down, and, at another, mud, as was before stated to be the case in the delta of the Mississippi; or at one time, when the volume and velocity of the stream are greatest, pebbles and sand

may be spread over a certain area, over which, when the waters are low, fine matter or chemical precipitates are formed. During inundations, the turbid current of fresh water often repels the sea for many miles; but when the river is low, salt water again occupies the same space. When two deltas are converging, the intermediate space is often, for reasons before explained, alternately the receptacle of different sediments derived from the converging streams (see p. 454). The one is, perhaps, charged with calcareous, the other with argillaceous matter; or one sweeps down sand and pebbles, the other impalpable mud. These differences may be repeated, with considerable regularity, until a thickness of hundreds of feet of alternating beds is accumulated. The multiplication, also, of shells and corals in particular spots, and for limited periods, gives rise occasionally to lines of separation, and divides a mass which might otherwise be homogeneous into distinct strata.

An examination of the shell marl now forming in the Scotch lakes, or the sediment termed 'warp,' which subsides from the muddy water of the Humber and other rivers, shows that recent deposits are often composed of a great number of extremely thin layers, either even or slightly undulating, and preserving a general parallelism to the planes of stratification. Sometimes, however, the laminæ in modern strata are disposed diagonally at a considerable angle, which appears to take place where there are conflicting movements in the waters. In January 1829 I visited, in company with Professor L. A. Necker, of Geneva, the confluence of the Rhone and Arve, when those rivers were very low, and were cutting channels through the vast heaps of débris thrown down from the waters of the Arve in the preceding spring. One of the sand-banks which had formed in the spring of 1828, where the opposing currents of the two rivers neutralised each other, and caused a retardation in the motion. had been undermined; and fig. 44 on the following page is an exact representation of the arrangement of laminæ exposed in a vertical section. The length of the portion here seen is about twelve feet, and the height five. The strata A A consist of irregular alternations of pebbles and sand in

undulating beds: below these are seams of very fine sand, B B, some as thin as paper, others about a quarter of an inch thick. The strata C C are composed of layers of fine greenish-grey sand as thin as paper. Some of the inclined beds will be seen to be thicker at their upper, others at their lower extremity, the inclination of some being very considerable.

Fig. 44.



Section of a sand-bank in the bed of the Arve at its confluence with the Rhone, showing the stratification of deposits where currents meet.

These layers must have accumulated one on the other by lateral apposition, probably when one of the rivers was very gradually increasing or diminishing in velocity, so that the point of greatest retardation caused by their conflicting currents shifted slowly, allowing the sediment to be thrown down in successive layers on a sloping bank. The same phenomenon is exhibited in older strata of all ages.*

If the bed of a lake or of the sea be sinking, whether at a uniform or an unequal rate, or oscillating in level during the deposition of sediment, these movements will give rise to a different class of phenomena, as, for example, to repeated alternations of shallow-water and deep-water deposits, each with peculiar organic remains, or to frequent repetitions of similar beds formed at a uniform depth, and enclosing the same organic remains, and to other results too complicated and varied to admit of enumeration here.

Formation of conglomerates.—Along the base of the Maritime Alps, between Toulon and Genoa, the rivers, with few exceptions, are now forming strata of conglomerate and sand. Their channels are often several miles in breadth, some of

* See Elements of Geology, 6th ed. p. 16, and Student's Elements, p. 17.

them being dry, and the rest easily forded for nearly eight months in the year, whereas during the melting of the snow they are swollen, and a great transportation of mud and pebbles takes place. In order to keep open the main road carried along the sea-coast from France to Italy, it was necessary to remove annually great masses of shingle brought down during the flood season. A portion of the pebbles are seen in some localities, as near Nice, to form beds of shingle along the shore, but the greater part are swept into a deep sea. The small progress made by the deltas of minor rivers on this coast need not surprise us, when we recollect that there is sometimes a depth of two thousand feet at a few hundred yards from the beach, as near Nice. Similar observations might be made respecting a large proportion of the rivers in Sicily, and, among others, respecting that which, immediately north of the port of Messina, hurries annually vast masses of granitic pebbles into the sea.

I may here conclude my remarks upon deltas, observing that, imperfect as is our information of the changes which they have undergone within the last three thousand years, they are sufficient to show how constant an interchange of sea and land is taking place on the face of our globe. In the Mediterranean alone, many flourishing inland towns, and a still greater number of ports, now stand where the sea rolled its waves since the era of the early civilisation of Europe. If we could compare with equal accuracy the ancient and actual state of all the islands and continents, we should probably discover that millions of our race are now supported by lands situated where seas and lakes prevailed in earlier ages. While in many districts land animals and forests now abound where ships once sailed, it is no less true, on the other hand, that inroads of the ocean and submergence of land by the sinking down of the earth's crust have taken place over equally wide areas. When all these revolutions, gradually brought about by aqueous and igneous agency, are duly considered, we shall, perhaps, acknowledge the justice of the conclusion of Aristotle, who declared that the whole land and sea on our globe periodically changed places.*

* See p. 22.

CHAPTER XX.

DESTROYING AND TRANSPORTING EFFECTS OF TIDES AND CURRENTS.

DIFFERENCES IN THE RISE OF THE TIDES—CAUSES OF CURRENTS—LAGULLAS AND GULF CURRENTS—CURRENT IN LAKE ERIE—SURFACE CURRENT INTO THE MEDITERRANEAN DUE TO EXCESS OF EVAPORATION—NO PERMANENT UNDER-CURRENT IN THE STRAITS OF GIBRALTAR, BUT TIDAL ACTION TO THE BOTTOM—CONTRAST OF TEMPERATURE BETWEEN THE MEDITERRANEAN AND ATLANTIC—CURRENTS IN THE BLACK SEA—VELOCITY OF CURRENTS—GENERAL OCEANIC CIRCULATION—ACTION OF THE SEA ON THE BRITISH COAST—SHETLAND ISLANDS—LARGE BLOCKS REMOVED—ISLES REDUCED TO CLUSTERS OF ROCKS—ORKNEY ISLES—WASTE OF EAST COAST OF SCOTLAND—AND EAST COAST OF ENGLAND—WASTE OF THE CLIFFS OF HOLDERNESS, NORFOLK, AND SUFFOLK—ECCLES CHURCH IN 1839 AND 1862—SAND-DUNES HOW FAR CHRONOMETERS—SILTING UP OF ESTUARIES—YARMOUTH ESTUARY—SUFFOLK COAST—DUNWICH—ESSEX COAST—ESTUARY OF THE THAMES—GOODWIN SANDS—COAST OF KENT—FORMATION OF THE STRAITS OF DOVER—SOUTH COAST OF ENGLAND—SUSSEX—HANTS—DORSET—PORTLAND—ORIGIN OF THE CHESIL BANK—TOR BAY—ST. MICHAEL'S MOUNT, CORNWALL—COAST OF BRITTANY.

ALTHOUGH the movements of great bodies of water, termed tides and currents, are in general due to very distinct causes, their effects cannot be studied separately; for they produce, by their joint action, aided by that of the waves, those changes which are objects of geological interest. These forces may be viewed in the same manner as we before considered rivers—first, as employed in destroying portions of the solid crust of the earth, and removing them to other places; secondly, as productive of new strata.

Tides.—It would be superfluous at the present day to offer any remarks on the cause of the tides. They are not perceptible in lakes or in most inland seas; in the Mediterranean even, deep and extensive as is that sea, they are scarcely sensible to ordinary observation, their effects being quite subordinate to those of the winds and currents. In some places, however, as in the Straits of Messina, there is an ebb and flow to the amount of two feet and upwards; at Naples of twelve or thirteen inches; and at Venice, according to

Rennel, of five feet.* In the Syrtes, also, of the ancients, two wide shallow gulfs, which penetrate very far within the northern coast of Africa between Carthage and Cyrene, the rise is said to exceed five feet.† The effect of the tide in the celebrated straits of Euripus in Greece is very remarkable. These straits at Chalcis or Negropont are only about fifty feet wide and twenty feet deep, and Captain Spratt observed during his survey of the Mediterranean that for about four days before and five after the full and new moon the tide runs with great regularity six hours to the north and then six hours to the south at a rate of several miles an hour. The rise and fall is about one foot on the southern side of the straits and as much as twenty-six inches on the northern. At other times he found that the tide was absorbed by the influence of local winds and was very irregular.

In islands remote from any continent, the ebb and flow of the ocean is very slight, as at St. Helena, for example, where it is rarely above three feet.‡ In any given line of coast, the tides are greatest in narrow channels, bays, and estuaries, and least in the intervening tracts where the land is prominent. Thus, at the entrance of the estuary of the Thames and Medway, the rise of the spring tides is eighteen feet; but when we follow our eastern coast from thence northward, towards Lowestoft and Yarmouth, we find a gradual diminution. until, at the places last mentioned, the highest rise is only seven or eight feet. From this point there begins again to be an increase, so that at Cromer, where the coast again retires towards the west, the rise is sixteen feet; and towards the extremity of the gulf called 'the Wash,' as at Lynn and in Boston Deeps, it is from twenty-two to twenty-four feet, and in some extraordinary cases twenty-six feet. From thence again there is a decrease towards the north, the elevation at the Spurn Point being from nineteen to twenty feet, and at Flamborough Head and the Yorkshire coast from fourteen to sixteen feet.§

At Milford Haven in Pembrokeshire, at the mouth of the

* Geog. of Herod. vol. ii. p. 331.

† Ibid. p. 328.

‡ Romme, Vents et Courans, vol. ii. p. 2. Rev. F. Fallows, Quart. Journ. of Science, March 1829.

§ The heights of these tides were given me by the late Captain Hewett, R.N.

Bristol Channel, the tides rise thirty-six feet; and at King-Road near Bristol, forty-two feet. At Chepstow on the Wye, a small river which opens into the estuary of the Severn, they reach fifty feet and sometimes sixty-nine, and even seventy-two feet.* A current which sets in on the French coast, to the west of Cape La Hague, becomes pent up by Guernsey, Jersey, and other islands, till the rise of the tide is from twenty to forty-five feet, which last height it attains at Jersey, and at St. Malo, a seaport of Brittany. The tides in the Basin of Mines, at the head of the Bay of Fundy in Nova Scotia, rise to the height of seventy feet. There are, however, some coasts where the tides seem to offer an exception to the rule above mentioned; for while there is scarcely any rise in the estuary of the Plata in South America, there is an extremely high tide on the open coast of Patagonia, farther to the south. Yet even in this region the tides reach their greatest elevation (about fifty feet) in the Straits of Magellan, and so far at least they conform to the general rule.

Causes of currents.—That movements of no inconsiderable magnitude should be impressed on a wide expanse of ocean, by winds blowing for many months in one direction, may easily be conceived, when we observe the effects produced in our own seas by the temporary action of the same cause. It is well known that a strong south-west or north-west wind invariably raises the tide to an unusual height along the west coast of England and in the Channel, and that a north-west wind of any continuance causes the Baltic to rise two feet and upwards above its ordinary level. Smeaton ascertained by experiment, that in a canal four miles in length, the water was kept up four inches higher at one end than at the other merely by the action of the wind along the canal; and the late Major Rennel informs us that a large piece of water, ten miles broad, and generally only three feet deep, has, by a strong wind, had its waters driven to one side, and sustained so as to become six feet deep, while the windward side was laid dry.†

* On the authority of Admiral Sir F. Beaufort, R.N.

† Rennel on the Channel Current.

As water, therefore, he observes, when pent up so that it cannot escape, acquires a higher level, so in a place *where it can escape*, the same operation produces a current; and this current will extend to a greater or less distance, according to the force by which it is produced.

In such large bodies of water as the North American lakes, the continuance of a strong wind in one direction often causes the accumulation of the water, on the leeward side; and while the equilibrium is being restored powerful currents are occasioned. In October 1833 a strong current in Lake Erie, caused partly by the set of the waters towards the outlet of the lake, and partly by the prevailing wind, burst a passage through the extensive peninsula called Long Point, and soon excavated a channel more than nine feet deep and nine hundred feet wide, which was afterwards widened and deepened.* On the opposite, or southern coast of this lake, in front of the town of Cleveland, the degradation of the cliffs had been so rapid for several years preceding a survey made in 1837 as to threaten many towns with demolition.†

Major Rennel‡ has divided currents according to their origin into drift and stream currents; the former being due to constant and prevalent winds impelling the surface water to leeward until it meets with some obstacle which stops it and occasions an accumulation, this accumulation then giving rise to a stream-current. The obstacle may be either land or banks or a stream-current already formed. A stream-current may be of any bulk, or depth, or velocity; a drift-current is shallow and rarely exceeds in velocity the rate of half a mile an hour.

One of the chief oceanic currents is that which flows through the Mozambique Channel, and there skirts the south-east coast of Africa, having a breadth of ninety miles and a velocity of between two and four miles an hour. On reaching the Cape, it is turned westward by the Lagullas, a great shoal or rather a submerged chain of mountains, which,

* From notes given me by Capt. Bayfield, R.N.

† Silliman's Journ. vol. xxxiv. p. 349.

‡ Investigation of the Currents of the Atlantic Ocean, page 21. London, 1832.

rising from a deep ocean, comes within 100 fathoms of the surface. The deflection of this current, says Rennel, proves that it is more than 100 fathoms deep, otherwise the main body of it would pass across the bank instead of being deflected westward, so as to flow round the Cape of Good Hope. It is then joined by a current from the south or from antarctic latitudes, and, continuing its course, takes a northerly direction along the western coast of Africa, till it reaches the Bight or Bay of Benin. There it is turned westward, partly by the form of the coast and partly perhaps by meeting the Guinea current, which runs from the north into the same great bay. From the centre of this bay proceeds what is called the equatorial current of the Atlantic, having a width of from 160 to 450 nautical miles, and holding a westerly course across that ocean which it traverses from the coast of Guinea to that of Brazil. The whole length is said to be about 4,000 geographical miles, and its velocity from twenty-five to seventy-nine miles per day, the mean rate being about thirty miles.

On approaching the N.E. promontory of South America, called Cape St. Roque, it divides itself into two parts, one portion of which pursues a southerly course along the coast of Brazil, while the principal part of it flows westward, and, skirting the coast of Guiana, is reinforced by the waters of the Amazons and Orinoco. After passing the island of Trinidad, it expands and contributes in some degree to raise the waters of the Caribbean Sea and Gulf of Mexico, which are also supposed to be heaped up by the blowing of the north-east trade winds—a combination of circumstances which gives rise to the Gulf-stream.

The last-mentioned current has already been alluded to in the twelfth chapter (p. 239) as moderating the cold of a large part of the northern hemisphere. A curious fact is related by General Sabine as illustrating the combined effects of the equatorial and Gulf currents last alluded to. He happened to visit the African coast in 1822, when a vessel was wrecked at Cape Lopez, near the equator, and the year after he was at Hammerfest, in Norway, near the North Cape of Europe, when casks of palm oil derived from the same wrecked

vessel were thrown on shore. They had crossed the Atlantic south of the line in a direction from east to west, made the circuit of the West Indian Islands, and then recrossed the Atlantic north of the line from west to east. The last or northern part of their course may possibly, says General Sabine, have been due not wholly to the original impulse of the Gulf-stream, but to the west and south-west winds which prevail to the northward of the trades.

From the above statements we may understand why Rennel has characterised some of the principal currents as oceanic rivers, which he describes as being from 50 to 250 miles in breadth, and having a rapidity exceeding that of the largest navigable rivers of the continents, and so deep as to be sometimes obstructed, and occasionally turned aside, by banks, the tops of which do not rise within forty, fifty, or even one hundred fathoms of the surface of the sea.*

Currents flowing alternately in opposite directions are occasioned by the rise and fall of the tides. The effect of this cause, as we shall see in the sequel, is most striking in estuaries and channels between islands.

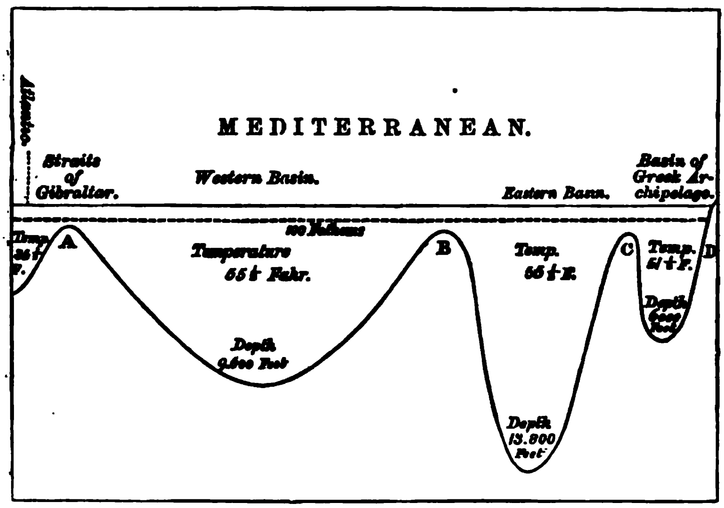
Current into the Mediterranean due to excess of evaporation.— Another cause of oceanic currents is evaporation by solar heat. Of this the current which sets constantly from the Atlantic into the Mediterranean is a good example. The late Admiral Smyth found, during his survey, that a central current ran constantly at the rate of from three to six miles an hour eastward into the inland sea, the body of water being three miles and a half wide. But there are also two lateral currents—one on the European, and one on the African side; each of them from a quarter of a mile to two miles broad, and flowing at about the same rate as the central stream. These lateral currents ebb and flow with the tide, setting alternately into the Mediterranean and into the Atlantic. But it is a generally received opinion that, in spite of their action, there is an excess of water flowing inwards, to make up for the loss which the Mediterranean suffers by evaporation. For the winds blowing from the shores of Africa are

* Rennel on Currents p. 58.

hot and dry, and the temperature of the air investing the great inland sea, as well as that of the water, is higher on an average than the eastern part of the Atlantic Ocean in the same latitude.

The western basin of the Mediterranean, or that lying to the west of Sicily, between A, B (fig. 45), was estimated

Fig. 45.



Section of the Mediterranean Basins.

A. Submarine ridge, about 167 fathoms deep, between Capes Trafalgar and Spartel.

B. Adventure and Medina Banks, about 200 fathoms deep, between Sicily and Africa.

C. Ridge, about 200 fathoms deep, between the Eastern Basin and Greek Archipelago.

D. Asia Minor.

by Captain Spratt in 1845 to have, at depths below one hundred fathoms, a temperature of about 20° F. higher than that of the Atlantic in the same latitude.* This extraordinary difference would be impossible but for the existence of a submarine barrier of rock (A, fig. 45) which

* Capt. Spratt estimated the temperatures of the two seas at 59½° and 39½°. Since then more perfect thermometers have been brought into use, which show a temperature of 55½° in the Mediterranean, and 35½° in the Atlantic. As however, this error affects both seas equally, it does not in any way vitiate the previous generalisation.

was found by Admiral Smyth to extend from Cape Trafalgar to Cape Spartel, which are only 22 miles apart. He ascertained that the crest of this ridge could in no part be lower than 220 fathoms from the surface; but Capt. Spratt informs me that the French surveyors, in their more recent surveys of 1854 and 1863, have proved that the deepest soundings, which are near the Tangiers side, do not exceed 167 fathoms. The ridge being from five to seven miles broad, the shallowest part of the continuous crest may even now have escaped observation, and it forms a parting wall by which the colder waters of the Atlantic are prevented from invading the Mediterranean.* It was formerly supposed that the saltness of the water increased in proportion to the depth; but Captain Spratt's observations do not bear out this conclusion, though the Ægean is slightly fresher at the surface near the Dardanelles, from which a current charged with much river water is constantly flowing.

The question was raised as long ago as 1673 by Dr. Smith, whether there is not a counter-under-current from the Mediterranean to the Atlantic, pouring back the surplus water which is over and above that required to counterbalance evaporation, and the idea of such a counter-current was again suggested in 1724 by the following circumstance. M. de L'Aigle, commander of a privateer called the Phœnix, of Marseilles, gave chase to a Dutch merchant-ship near Ceuta Point, and coming up with her in the middle of the gut, between Tarifa and Tangier, gave her one broadside, which directly sunk her. A few days after, the sunken ship, with her cargo of brandy and oil, was cast ashore near Tangier, which is at least four leagues to the westward of the place where she went down, and to which she must have floated in a direction contrary to the course of the *central* current.† This fact, however, affords no evidence of an under-current, because the ship, when it approached the coast, would necessarily be within the influence of a lateral current, which running westward twice every twenty-four hours, might have brought back the vessel to Tangier.

* Capt. Spratt, Travels and Researchesin Crete, 1865.
† Phil. Trans. 1724.

An attempt to test the truth of a return under-current was made in 1870, under the superintendence of Captain Calver, R.N., in command of the surveying vessel 'Porcupine' sent out by the Admiralty. Dr. Carpenter, who accompanied the expedition, inferred from the experiments then made* that there was a constant current flowing at the depth of 250 fathoms out of the Mediterranean, an opinion opposed to that which I had expressed in my former edition (1867, p. 563), as such a current appeared to me irreconcilable with the shallowness of the water over the submarine barrier before mentioned; and I found that Captain Spratt, to whom I was indebted for much of my former knowledge, agreed with me in thinking that the proofs of the permanent under-current insisted upon by Dr. Carpenter were inconclusive, though he pointed out at the same time that 'in such a strait as that of Gibraltar, where there are *tidal influences* combined with the general insets from the Atlantic, an under-current at certain times is a possibility.'† Last autumn the Admiralty, in further pursuance of the observations of 1870, sent out the surveying vessel 'Shearwater,' commanded by Captain Nares, R.N., and provided with more perfect apparatus for making experiments upon the under-current. From the report of Captain Nares, kindly lent me by Admiral Richards, we learn that the outward movement observed by the 'Porcupine' below the inflowing current is, not a permanent under-current, but the result of the Mediterranean tide, which extends to the bottom of the Straits running alternately for several hours westward and for an equal number of hours eastward, according to the flood and ebb of the tide, as shown by the rise and fall of the water on the shore.

This tide, when in a direction opposed to that of the surface current which flows in from the Atlantic, checks to a certain extent that influx, and when aided by easterly winds was found by Captain Nares to cause, even at the surface, a set to the westward. Its action appears, however, to be much more regular in the depths of the Straits where it is less interfered with either by winds or by the surface inflow.

* See Royal Society Proc. vol. xix. 1870, p. 146.

† Royal Soc. Proc. vol. xix. 1871, p. 546.

On comparing the results of the experiments made by the surveying officers in the two expeditions, I find nothing irreconcilable or antagonistic. The outward movement reported by Captain Calver is confirmed by Captain Nares, with the additional fact that, during the ebb of the tide this movement is reversed, thus proving that the under-current is the effect of tidal action. Captain Nares states that the bottom water in the strait 'ran to the westward more rapidly with the flood, than it ran to the eastward with the ebb.' But he does not lay much stress on this point; and Admiral Richards informs me, that the observations of the 'Shearwater' lasting only six days, and chiefly during the prevalence of easterly winds, were in his opinion too few to decide whether the volume of water carried out to the Atlantic was in excess of that carried in.

The Black Sea being situated in a higher latitude than the Mediterranean, and being the receptacle of rivers flowing from the north, is much colder, and its loss by conversion into vapour less considerable. It contributes a steady supply of water to the Mediterranean, by a current flowing outwards, for the most part of the year, through the Dardanelles at a rate of two or three miles an hour. The discharge, however, at the Bosphorus into the sea of Marmora is so small, when compared to the volume of water carried in by rivers, as to imply a great amount of evaporation even in the Black Sea.

There has been some difficulty in explaining how the Black Sea maintains its salinity in spite of the vast body of fresh water brought down into it by rivers. But some light is thrown upon this point by Captain Spratt's experiments at Constantinople and Kertch during the years 1853 to 1856. It was then ascertained that although a current of the Black Sea flows for a great part of the year across the Sea of Marmora and through the Dardanelles, yet there is for several days in the year a strong reverse current into the Black Sea from the Mediterranean.* This reverse current occurs mainly during the autumn and winter months, when the Black Sea rivers are at their lowest, and when strong westerly gales in the Mediterranean and Ægean raise the

* Spratt's Crete, vol. ii. p. 349.

waters of the latter to a higher level than the Black Sea. In these cases the influx is even greater than the outflowing current at other periods, and thus maintains in the sea of Marmora a salinity equal to that of the Mediterranean, and in the Black Sea rather more than half that amount. The depth of the ridge across the Bosphorus or channel of Constantinople is not more than 20 fathoms, and that of the Dardanelles about 30, so that the depth of the ordinary currents carried eastward by this cause is limited by the shallowness of these outlets.

Evaporation by solar heat, besides affecting the level of adjoining seas in the way above mentioned, gives origin, by the formation of aqueous vapour and rain, to all the rivers which drain the land, and some of these are of such magnitude as to augment the volume and velocity of great oceanic currents. Thus the river Amazons, as General Sabine observed in 1822, preserves a velocity of nearly three miles an hour at a distance of upwards of 300 miles from its mouth, its original direction being scarcely altered, and the fresh water having only become partially mixed with that of the ocean. The river Plate, says Rennel, has still a velocity of a mile an hour, and a breadth of more than 800 miles, at a distance of not less than 600 miles from its mouth.

Greatest velocity of currents.—The ordinary velocity of the principal currents of the ocean is from one to three miles per hour; but when the boundary lands converge, large bodies of water are driven gradually into a narrow space, and then, wanting lateral room, are compelled to raise their level. Whenever this occurs, their velocity is much increased. The current which runs through the Race of Alderney between the island of that name in the English Channel and the main land, has a velocity of about eight miles an hour. Captain Hewett found that in the Pentland Firth, the stream, in ordinary spring tides, runs ten miles and a half an hour, and about thirteen miles during violent storms. The greatest velocity of the tidal current through the 'Shoots' or New Passage, in the Bristol Channel, is fourteen English miles an hour; and Captain King observed, in his survey of the Straits of Magellan, that the tide ran at the same rate

through the 'First Narrows,' and about eight geographical miles an hour in other parts of those straits.

When currents have been set in motion by some one or all of the forces enumerated in this chapter, namely, the winds, the tides, evaporation, and the influx of rivers, another cause comes into play in modifying their direction. I allude to the rotation of the earth on its axis, which, however, can only act when the current so raised happens to be from south to north or from north to south.

The principle on which this cause operates is probably familiar to the reader, as it has long been recognised in the case of the trade winds. Without enlarging, therefore, on the theory, it will be sufficient to offer an example of the mode of action alluded to. When a current flows from the Cape of Good Hope towards the Gulf of Guinea, it consists of a mass of water, which, on doubling the Cape, in lat. 35°, has a rotatory velocity of about 800 miles an hour; but when it reaches the line, where it turns westward, it has arrived at a parallel where the surface of the earth is whirled round at the rate of 1,000 miles an hour, or about 200 miles faster. If this great mass of water was transferred suddenly from the higher to the lower latitude, the deficiency of its rotatory motion, relatively to the land and water with which it would come into juxtaposition, would be such as to cause an apparent motion of the most rapid kind (of no less than 200 miles an hour) from east to west.

In the case of such a sudden transfer, the eastern coast of America, being carried round in an opposite direction, might strike against a large body of water with tremendous violence, and a considerable part of the continent might be submerged. The disturbance does not occur, because the water of the stream, as it advances gradually into new zones of the sea which are moving more rapidly, acquires by friction an accelerated velocity. Yet as this motion is not imparted instantaneously, the fluid is unable to keep up with the full speed of the new surface over which it is successively brought. Hence, to borrow the language of Herschel, when he speaks of the trade winds, 'it lags or hangs back, in a direction opposite to the earth's rotation, that is, from east

to west;' and thus a current, which would have run simply northwards from the Antarctic Ocean to the Equator but for the rotation, may acquire a relative direction towards the west.

A striking example in the northern hemisphere of a similar deflection westward is afforded by the polar current, which, loaded with floating ice, flows southwards from the Arctic Sea in the neighbourhood of Spitzbergen, having a breadth of between 40 and 50 miles, and after passing the southern extremity of Greenland, then trends towards the west under the influence of the earth's rotation, that westerly tendency increasing as it enters latitudes of increased rotatory velocity. Here it unites with other cold and ice-laden currents from Baffin's Bay, and then continues its course towards the Labrador coast, and rounding Newfoundland descends along the eastern coast of the United States at a rate varying from half a mile to three quarters of a mile an hour, forming a cold current about 250 fathoms in depth inside or westward of the Gulf-stream. This last stream affords an example of a motion exactly the converse of the Labrador current. Flowing at first from about lat. 20° N., it is impressed with a velocity of rotation of about 940 miles an hour, and runs to the lat. 40°, where the earth revolves only at the rate of 766 miles, or 174 miles slower. In this case a relative motion of an opposite kind results; and the current retains an excess of rotatory velocity, tending continually to deflect it eastward. The two currents therefore have a tendency to keep separate, the one from an excess and the other from a deficiency of rotatory motion. In the region where the two streams run side by side we find the remarkable phenomenon known as the cold wall, an almost vertical division between the warmer waters of the Gulf-stream, which range from 60° to 85° Fahr., and the Labrador current, which, even at its surface, often has a temperature in the winter months 30° Fahr. lower than the warm stream flowing past it. Each of these currents has its own peculiar fauna, and Professor Bache found that the line of demarcation between them becomes more defined at the depth of 50 fathoms than at the surface. At what depth owing to condensation the Labrador current may acquire such specific gravity as to cause it to pass under the warmer

stratum is not yet well ascertained, but the low temperature of 40° Fahr. found off Florida at the depth of 300 fathoms while the surface has a temperature of 80° Fahr. would seem to be due to the action of the cold under-current.

This is one of the best illustrations of the grand scale on which the Arctic waters may restore equilibrium in regard to level and temperature by transferring bodily southwards large masses of cold water, not creeping along the bottom, but as above stated 250 fathoms in depth, and having all the characters of ordinary currents which have no doubt been created by the action of the wind and tide, and which do not derive their motion from mere differences in temperature and specific gravity between polar and equatorial waters. Those winds by which large ice-floes after remaining for weeks in certain bays or coasts are made to shift their quarters must give rise to drift-currents, and these to stream-currents; and if the Gulf-stream and other flows of warmer water from equatorial regions pour into the Arctic basin, they must escape in such streams as that seen on the coast of Labrador. The shallowness of Behring's Straits, which are only of the depth of those of Dover, would prevent any large outflow into the Pacific; and as the only known outlets from this cul-de-sac will therefore be through Baffin's Bay and between Spitzbergen and Greenland, this may account for the force and magnitude of the Labrador current.

Between Iceland and the Faroe Islands the Gulf-stream and Polar current fight, as Dr. Petermann expresses it,* for the mastery; and the result of this struggle is a sea striped with warm and cold areas, as was shown by Lord Dufferin in 1856, and by Wallich in the 'Bulldog' expedition commanded by Sir Leopold M'Clintock in 1860. These facts are particularly interesting as having been fully confirmed by the late deep-sea dredgings between the Faroe and Shetland islands. Here Drs. Carpenter and Wyville Thomson found two areas which, although having the same temperature of 51° Fahr. at the surface, began to differ at the depth of 150 fathoms. The one area, inhabited by its own peculiar fauna, comprising large foraminifera and siliceous sponges of more

* Der Golf-strom, Geographische Mittheilungen. Justus Perthes. Band 16. 1870.

southern types, lost very little in temperature below 150 fathoms, and at a depth of 500 fathoms had still a warmth of 45° Fahr. The other, or cold area, lost temperature rapidly after the depth of 100 fathoms, and at one place below 350 fathoms was colder than the freezing point of fresh water. The water in this area gave proof of its northern origin by containing echinoderms and other organic remains proper to Norwegian and still higher latitudes. It has been objected that we have no right to attribute to the influence of the Gulf-stream the warmth of all the water which we may find in the Northern Atlantic above the normal temperature of the latitude. But when recognising the influence of that stream in the Atlantic we do not, as Dr. Petermann justly observes, refer the whole of it to the current which flows out of the Gulf of Mexico, or deny that it has received accessions upon its way: we rather retain the name of Gulf-stream just as we do that of a river from its source to its delta, although many tributaries coming from different regions may have swollen and modified its volume. The main fact that the Gulf-stream does reach the shores of Europe is proved by the well-known drifting of West Indian seeds to the coast of Ireland (see Vol. II. Chap. XL.), and doubtless the south-westerly winds which prevail so largely in the Atlantic must do much in propelling the superficial waters in the same direction as they are carried by the regular currents.

Oceanic circulation.—Besides those sensible currents arising from the various causes already mentioned, a theory of general oceanic circulation first propounded by Maury has lately been brought into prominence by Dr. Carpenter in order to account for the cold found at great depths both in temperate and tropical regions. Captain Shortland, in his line of soundings made in 1868 for the laying down of the electric cable between Aden and Bombay, found a temperature of 34°·3 Fahr. at a depth of 1,800 fathoms (11,400 feet), and in the cruise of the 'Porcupine' in 1869 the bottom temperature between latitudes 50° and 70° N. was in several cases found to be below the freezing point of fresh water. That these low temperatures cannot be caused by mere depth is evident from the fact that in the Mediterranean soundings have

been made to the depth of 13,800 feet, or nearly as deep as the Alps are high, without ever reaching a temperature below 55° Fahr. When we reflect therefore that the Aden line of telegraph is fifteen degrees north of the equator, and that cold water can only come to that spot from the southern hemisphere, we are brought to the conclusion that the whole of the equatorial abysses of the ocean are in some part at least traversed by a continuous mass of water not much above 32° Fahr.

It is an acknowledged fact that when salt water in arctic and antarctic latitudes is cooled to a temperature below that at which fresh water freezes, its greater specific gravity causes it to sin but it does not become ice until it attains the temperature of 27° Fahr., or even 25° Fahr. if the saltness somewhat exceeds the average. If on arriving at the bottom it finds there water of less specific gravity it will displace it, and it is inferred that thus a movement will be induced towards warmer latitudes, producing what Dr. Carpenter has well characterised as a 'creeping flow.' The direction of this movement must be governed by local conditions or the shape of the bed of the ocean, and it may take years in traversing the ninety degrees between the poles and the equator. Its progress may be so gradual as not to cause what in ordinary language would be termed oceanic currents, and may even be consistent with that perfect stillness found generally to prevail in the abysses of the ocean. Captain Spratt reminds us that during the soundings taken across the Atlantic the sounding line on several occasions coiled itself upon the sinker when some 200 or 300 fathoms more than the actual depth happened accidentally or intentionally to have been paid out from the ship, and thus the coils came up in a bunch together round the deep sea lead. Such facts tell strongly against the existence of anything like a sensible current, but on the other hand they do not prove the water to be motionless, because the tension of the hempen sounding-line might be such as to afford some resistance to a slight and almost imperceptible movement, such as might still be sufficient in the course of time to convey cold water to all those submarine regions where there is a free communication, or where no continuous shoal or chain of submarine mountains intervenes.

If such a movement be taking place, however slowly, it must be counterbalanced by a return of water back from the equator to the poles, and how this may be readily effected will be evident to the reader after what has been said of the powerful effect of the winds on the surface of the ocean. It is quite unnecessary to seek for some recondite cause, such as the expansion of water by heat in the equatorial zone raising the level of the sea and causing a flow to the poles down a gently inclined plane. This theory, which is by no means a new one, was considered by Sir John Herschel in his 'Physical Geography,' where he shows that the slope between tropical and temperate latitudes, a distance of 3,000 or 4,000 miles, would be so insignificant that the accelerating force produced would not exceed one two-millionth part of gravity, and would be inefficient as a motor power. Moreover it remains to be proved as a matter of fact whether the surface of the equatorial ocean is really elevated by solar heat above the level of the polar seas. The superficial temperature averages 79°·8 Fahr. for the whole year, so that the amount of evaporation may be expected to exceed that of the Mediterranean, which only attains an equally high temperature at the surface during the extreme heat of summer, and falls about twenty-five degrees lower in winter. If then in spite of this smaller quantity of heat it is only by an indraught from the Atlantic that the level of the inland sea can be sustained, it may be questioned whether, taking into account evaporation, barometric pressure, floating icebergs, and other conflicting and compensating causes in the open ocean, we have sufficient data to enable us to infer in what direction a movement would be induced. Indeed it seems almost idle to be speculating upon supposed undercurrents so imperceptible as not to be tested by a sounding-line, and surface flows depending upon a slope only capable of producing an accelerating force of one two-millionth part of gravity, when we have known currents flowing for thousands of miles from north to south, and south to north, which reach for hundreds of fathoms, from the surface to the bottom of deep seas, and flow so many miles a day as to render them capable of transferring in short periods of time great volumes of water of different temperatures from one part of the globe to another.

DESTROYING AND TRANSPORTING POWER OF CURRENTS.

After these preliminary remarks on the nature and causes of currents, their velocity and direction, we may next consider their action on the solid materials of the earth. We shall find that their efforts are, in many respects, strictly analogous to those of rivers. I have already treated, in the third chapter, of the manner in which currents sometimes combine with ice, in carrying mud, pebbles, and large fragments of rock to great distances. Their operations are more concealed from our view than those of rivers, but extend to wider areas, and are therefore of more geological importance.

Action of the sea on the British coast—Shetland Islands.—If we follow the eastern and southern shores of the British Islands, from our Ultima Thule in Shetland to the Land's End in Cornwall, we shall find evidence of a series of changes since the historical era, very illustrative of the kind and degree of force exerted by tides and currents co-operating with the waves of the sea. In this survey we shall have an opportunity of tracing their joint power on islands, promontories, bays, and estuaries; on bold, lofty cliffs, as well as on low shores; and on every description of rock and soil, from granite to blown sand.

The northernmost group of the British Islands, the Shetland, are composed of a great variety of rocks, including granite, gneiss, mica-slate, serpentine, greenstone, and many others, with some secondary rocks, chiefly sandstone and conglomerate. These islands are exposed continually to the uncontrolled violence of the Atlantic, for no land intervenes between their western shores and America. The prevalence, therefore, of strong westerly gales, causes the waves to be sometimes driven with irresistible force upon the coast, while there is also a current setting from the north. The spray of the sea aids the decomposition of the rocks, and prepares them to be breached by the mechanical force of the waves. Steep cliffs are hollowed out into deep caves and lofty arches; and almost every promontory ends in a cluster of rock, imitating the forms of columns, pinnacles, and obelisks.

Drifting of large masses of rock.—Modern observations show that the reduction of continuous tracts to such insular masses is a process in which nature is still actively engaged. 'The isle of Stenness,' says Dr. Hibbert, 'presents a scene of unequalled desolation. In stormy winters, huge blocks of stones are overturned, or are removed from their native beds, and hurried up a slight acclivity to a distance almost incredible. In the winter of 1802, a tabular-shaped mass, eight feet two inches by seven feet, and five feet one inch thick, was dislodged from its bed, and removed to a distance of from eighty to ninety feet. I measured the recent bed from which a block had been carried away the preceding winter (A.D. 1818), and found it to be seventeen feet and a half by seven feet, and the depth two feet eight inches. The removed mass had been borne to a distance of thirty feet, when it was shivered into thirteen or more lesser fragments, some of which were carried still farther, from 30 to 120 feet. A block, nine feet two inches by six feet and a half, and four feet thick, was hurried up the acclivity to a distance of 510 feet.'*

At Northmavine, also, angular blocks of stone, some of which are represented in the annexed figure 46, have been removed in a similar manner to considerable distances by the waves of the sea.

Effects of lightning.—In addition to numerous examples of masses detached and driven by the waves, tides, and currents from their place, some remarkable effects of lightning are recorded in these isles. At Funzie, in Fetlar, about the middle of the last century, a rock of mica-schist, 105 feet long, ten feet broad, and in some places four feet thick, was in an instant torn by a flash of lightning from its bed, broken into three large and several smaller fragments. One of these, twenty-six feet long, ten feet broad, and four feet thick, was simply turned over. The second, which was twenty-eight feet long, seventeen broad, and five feet in thickness, was hurled across a high point to the distance of fifty yards. Another broken mass, about forty feet long, was thrown still

* Description of Shetland Isles, p. 527. Edin. 1822, to which work I am indebted for the following representations of rocks in the Shetland Isles.

farther, but in the same direction, quite into the sea. There were also many smaller fragments scattered up and down.*

When we thus see electricity co-operating with the violent movements of the ocean in heaping up piles of shattered rocks on dry land and beneath the waters, we cannot but admit that a region which shall be the theatre, for myriads of ages, of the action of such disturbing causes, might present, at some future period, if upraised far above the bosom of the deep, a scene of havoc and ruin that may compare with any now found by the geologist on the surface of our continents.

Fig. 46.

Stony fragments drifted by the sea. Northmavine, Shetland.

In some of the Shetland Isles, as on the west of Meikle Roe, dikes, or veins of soft granite, have mouldered away; while the matrix in which they were enclosed, being of the same substance, but of a firmer texture, has remained unaltered. Thus, long narrow ravines, sometimes twenty feet wide are laid open, and often give access to the waves. After describing some huge cavernous apertures into which the sea flows for 250 feet in Loeness, Dr. Hibbert, writing in 1822, enumerates other ravages of the ocean. 'A mass of rock, the average dimensions of which may perhaps be rated at twelve or thirteen feet square, and four and a half or five in thickness, was first moved from its bed, about fifty years ago, to a distance of thirty feet, and has since been twice turned over.'

Passage forced by the sea through porphyritic rocks.—'But

* Dr. Hibbert, from MSS. of Rev. George Low, of Fetlar.

the most sublime scene is where a mural pile of porphyry, escaping the process of disintegration that is devastating the coast, appears to have been left as a sort of rampart against the inroads of the ocean;—the Atlantic, when provoked by wintry gales, batters against it with all the force of real artillery—the waves having, in their repeated assaults, forced themselves an entrance. This breach, named the Grind of the Navir (fig. 47), is widened every winter by the over-

Fig. 47.

Grind of the Navir—passage forced by the sea through rocks of hard porphyry.

whelming surge that, finding a passage through it, separates large stones from its sides, and forces them to a distance of no less than 180 feet. In two or three spots, the fragments which have been detached are brought together in immense heaps, that appear as an accumulation of cubical masses, the product of some quarry.' *

It is evident from this example, that although the greater indestructibility of some rocks may enable them to withstand, for a longer time, the action of the elements, yet they cannot permanently resist. There are localities in Shetland in which rocks of almost every variety of mineral composition are suffering disintegration; thus the sea makes great inroads on the clay slate of Fitfel Head, on the serpentine

* Hibbert, p. 528.

of the Vord Hill in Fetlar, and on the mica-schist of the Bay of Trieste, on the east coast of the same island, which decomposes into angular blocks. The quartz rock on the

Fig. 48.

Granitic rocks named the Drongs, between Papa Stour and Hillswick Ness.

east of Walls, and the gneiss and mica-schist of Garthness, suffer the same fate.

Destruction of islands.—Such devastation cannot be incessantly committed for thousands of years without dividing

Fig. 49.

Granitic rocks to the south of Hillswick Ness, Shetland.

islands, until they become at last mere clusters of rocks, the last shreds of masses once continuous. To this state many appear to have been reduced, and innumerable fantastic

forms are assumed by rocks adjoining these islands to which the name of Drongs is applied, as it is to those of similar shape in Feroe.

The granitic rocks (fig. 48) between Papa Stour and Hillswick Ness afford an example. A still more singular cluster of rocks is seen to the south of Hillswick Ness (fig. 49), which presents a variety of forms as viewed from different points, and has often been likened to a small fleet of vessels with spread sails.* We may imagine that in the course of time Hillswick Ness itself may present a similar wreck, from the unequal decomposition of the rocks whereof it is composed, consisting of gneiss and mica-schist traversed in all directions by veins of felspar-porphyry.

Midway between the groups of Shetland and Orkney is Fair Island, said to be composed of sandstone with high perpendicular cliffs. The current runs with such velocity, that during a calm, and when there is no swell, the rocks on its shores are white with the foam of the sea driven against them. The Orkneys, if carefully examined, would probably illustrate our present topic as much as the Shetland group. The north-east promontory of Sanda, one of these islands, has been cut off in modern times by the sea, so that it became what is now called Start Island, where a lighthouse was erected in 1807, since which time the new strait has grown broader.

East coast of Scotland.—To pass over to the main land of Scotland, we find that in Inverness-shire there have been inroads of the sea at Fort George, and others in Morayshire, which have swept away the old town of Findhorn. On the coast of Kincardineshire, an illustration was afforded, at the close of the last century, of the effect of promontories in protecting a line of low-shore. The village of Mathers, two miles south of Johnshaven, was built on an ancient shingle beach, protected by a projecting ledge of limestone rock. This was quarried for lime to such an extent that the sea broke through, and in 1795 carried away the whole village in one night, and penetrated 150 yards inland, where it has maintained its ground ever since, the new village having

* Hibbert, p. 519.

been built farther inland on the new shore. In the Bay of Montrose, we find the North Esk and the South Esk rivers pouring annually into the sea large quantities of sand and pebbles; yet they have formed no deltas, for the waves, aided by the current, setting across their mouths, sweep away all the materials. Considerable beds of shingle, brought down by the North Esk, are seen along the beach.

Proceeding southwards, we learn that at Arbroath, in Forfarshire, which stands on a rock of red sandstone, gardens and houses have been carried away since the commencement of the present century by encroachments of the sea. In the same county, at Button Ness, it had become necessary before 1828, to remove the lighthouses at the mouth of the estuary of the Tay, which were built on a tract of blown sand, the sea having encroached for three quarters of a mile.

Estuary of the Tay—Bell-Rock Lighthouse.—The combined power which waves and currents can exert in *estuaries* (a term which I confine to bays entered both by rivers and the tides of the sea) was remarkably exhibited during the building of the Bell-Rock Lighthouse, off the mouth of the Tay. The Bell Rock is a sunken reef, consisting of red sandstone, being from twelve to sixteen feet under the surface at high water, and about twelve miles from the mainland. At the distance of 100 yards, there is a depth, in all directions, of two or three fathoms at low water. In 1807, during the erection of the lighthouse, six large blocks of granite, which had been landed on the reef, were removed by the force of the sea, and thrown over a rising ledge to the distance of twelve or fifteen paces; and an anchor, weighing about 22 cwt., was thrown up upon the rock.* Mr. Stevenson informs us, moreover, that drift stones, measuring upwards of thirty cubic feet, or more than two tons' weight, have, during storms, been often cast upon the rock from the deep water.†

Coast of Fife and Firth of Forth.—On the coast of Fife, at St. Andrew's, a tract of land, said to have intervened between the castle of Cardinal Beaton and the sea, has been entirely

* Account of Erection of Bell-Rock Lighthouse, p. 163.

† Ed. Phil. Journ. vol. iii. p. 54. 1820.

swept away, as were the last remains of the Priory of Crail, in 1803. On both sides of the Firth of Forth, land has been consumed; at North Berwick in particular, and at Newhaven, where an arsenal and dock, built in the reign of James IV., in the fifteenth century, has been overflowed.

East coast of England.—If we now proceed to the English coast, we find records of numerous lands having been destroyed in Northumberland, as those near Bamborough and Holy Island, and at Tynemouth Castle, which now overhangs the sea, although formerly separated from it by a strip of land. At Hartlepool, and several other parts of the coast of Durham composed of magnesian limestone, the sea has made considerable inroads.

Coast of Yorkshire.—Almost the whole coast of Yorkshire, from the mouth of the Tees to that of the Humber, is in a state of gradual dilapidation. That part of the cliffs which consists of lias, the oolite series, and chalk, decays slowly. These rocks present abrupt and naked precipices, often 300 feet in height; and it is only at a few points that the grassy covering of the sloping talus marks a temporary relaxation of the erosive action of the sea. The chalk cliffs are worn into caves and needles in the projecting headland of Flamborough, where they are decomposed by the sea spray, and slowly crumble away. But the waste is most rapid between that promontory and Spurn Point, or the coast of Holderness, as it is called, a tract consisting of beds of clay, gravel, sand, and chalk rubble. The argillaceous beds which are irregularly intermixed cause many springs to be thrown out, and this facilitates the undermining process, the waves beating against them, and a strong current setting chiefly from the north. The wasteful action is very conspicuous at Dimlington Height, the loftiest point in Holderness, where the beacon stands on a cliff 146 feet above high water, composed of clay, with pebbles scattered through it.* 'For many years,' says Professor Phillips, 'the rate at which the cliffs recede from Bridlington to Spurn, a distance of thirty-six miles, has been found by measurement to equal on an average two and a quarter yards annually, which upon thirty-six miles of coast

* Phillips's Geology of Yorkshire, p. 61.

would amount to about thirty acres a year. At this rate, the coast, the mean height of which above the sea is about forty feet, has lost one mile in breadth since the Norman Conquest, and more than two miles since the occupation of York (Eboracum) by the Romans.' * The extent of this denudation, as estimated by the number of cubic feet of matter removed annually, will be again spoken of in Chapter XXII.

In the old maps of Yorkshire, we find spots, now sand-banks in the sea, marked as the ancient sites of the towns and villages of Auburn, Hartburn, and Hyde. 'Of Hyde,' says Pennant, 'only the tradition is left; and near the village of Hornsea, a street called Hornsea Beck has long since been swallowed.' † Owthorne and its church have also been in great part destroyed, and the village of Kilnsea; but these villages have been rebuilt farther inland. The annual rate of encroachment at Owthorne for several years preceding 1830 is stated to have averaged about four yards. Not unreasonable fears are entertained that at some future time the Spurn Point will become an island, and that the ocean, entering into the estuary of the Humber, will cause great devastation.‡ Pennant, after speaking of the silting up of some ancient ports in that estuary, observes, 'But, in return, the sea has made most ample reprisals; the site, and even the very names of several places, once towns of note upon the Humber, are now only recorded in history. Ravensper was at one time a rival to Hull (Madox, Ant. Exch. i. 422), and a port so very considerable in 1332, that Edward Baliol and the confederated English barons sailed from hence to invade Scotland; and Henry IV., in 1399, made choice of this port to land at, to effect the deposal of Richard II.; yet the whole of this has long since been devoured by the merciless ocean; extensive sands, dry at low water, are to be seen in their stead.' §

Pennant describes Spurn Head as a promontory in the form

* Rivers, Mountains, and Sea-coast of Yorkshire, p. 122. 1853, London.

† Arctic Zoology, vol. i. p. 10. Introduction

‡ Phillips's Geology of Yorkshire, p. 60.

§ Arctic Zoology, vol i. p. 13. Introduction.

of a sickle, and says the land, for some miles to the north, was 'perpetually preyed on by the fury of the German Sea, which devours whole acres at a time, and exposes on the shores considerable quantities of beautiful amber.'

Lincolnshire.—The maritime district of Lincolnshire consists chiefly of lands that lie below the level of the sea, being protected by embankments. Some of the fens were embanked and drained by the Romans; but after their departure the sea returned, and large tracts were covered with beds of silt containing marine shells, now again converted into productive lands. Many dreadful catastrophes by incursions of the sea are recorded, whereby several parishes have been at different times overwhelmed.

Norfolk.—The decay of the cliffs of Norfolk and Suffolk is incessant. At Hunstanton, on the north, the undermining of the lower arenaceous beds at the foot of the cliff, causes masses of red and white chalk to be precipitated from above. Between Hunstanton and Weybourne, low hills, or dunes, of blown sand, are formed along the shore, from fifty to sixty feet high. They are composed of dry sand, bound in a compact mass by the long creeping roots of the plant called Marram (*Arundo arenaria*). Such is the present set of the tides that the harbours of Clay, Wells, and other places are securely defended by these barriers; affording a clear proof that it is not the strength of the material at particular points that determines whether the sea shall be progressive or stationary, but the general contour of the coast.

The waves constantly undermine the low chalk cliffs, covered with sand and clay, between Weybourne and Sheringham, a certain portion of them being annually removed. At the latter town I ascertained, in 1829, some facts which throw light on the rate at which the sea gains upon the land. It was computed, when the present inn was built, in 1805, that it would require seventy years for the sea to reach the spot: the mean loss of land being calculated, from previous observations, to be somewhat less than one yard annually. The distance between the house and the sea was fifty yards; but no allowance was made for the slope of the ground being *from* the sea, in consequence of which the waste was natur-

ally accelerated every year, as the cliff grew lower, there being at each succeeding period less matter to remove when portions of equal area fell down. Between the years 1824 and 1829, no less than seventeen yards were swept away and only a small garden was then left between the building and the sea. There was, in 1829, a depth of twenty feet (sufficient to float a frigate) at one point in the harbour of that port, where, only forty-eight years before, there stood a cliff fifty feet high, with houses upon it! If once in half a century an equal amount of change were produced suddenly by the momentary shock of an earthquake, history would be filled with records of such wonderful revolutions of the earth's surface; but if the conversion of high land into deep sea be gradual, it excites only local attention. The flag-staff of the Preventive Service station, on the south side of this harbour, was thrice removed inland between the years 1814 and 1829, in consequence of the advance of the sea.

Farther to the south we find cliffs, composed, like those of Holderness before mentioned, of alternating strata of blue clay, gravel, loam, and fine sand. Although they sometimes exceed 300 feet in height, the havoc made on the coast is most formidable. The whole site of ancient Cromer now forms part of the German Ocean, the inhabitants having gradually retreated inland to their present situation, whence the sea still threatens to dislodge them. In the winter of 1825, a fallen mass was precipitated from near the lighthouse, which covered twelve acres, extending far into the sea, the cliffs being 250 feet in height.* The undermining by springs has sometimes caused large portions of the upper part of the cliffs, with houses still standing upon them, to give way, so that it is impossible, by erecting breakwaters at the base of the cliffs, permanently to ward off the danger. Mr. Redman states that during the twenty-three years which elapsed between the Ordnance Survey of 1838 and the year 1861, a portion of the cliff, composed of sand and clay, between Cromer and Mundesley, receded 330 feet, amounting to a mean annual waste of fourteen feet; and the cliff at

* Taylor's Geology of East Norfolk, p. 32.

Happisburgh has, according to his estimate, wasted at the rate of about seven feet a year for sixty years preceding 1864.*

On the same coast, says Mr. R. C. Taylor, the ancient villages of Shipden, Wimpwell, and Eccles have disappeared; several manors and large portions of neighbouring parishes having, piece after piece, been swallowed up; nor has there been any intermission, from time immemorial, in the ravages of the sea along a line of coast twenty miles in length, on

Fig. 50.

Tower of the buried Church of Eccles, Norfolk, A.D. 1839.

The inland slope of the hills of blown sand is shown in this view, with the lighthouse of Hasborough, N.W. of the tower, in the distance.

which these places stood.† Of Eccles, however, a monument still remains in the ruined tower of the old church. So early as 1605 the inhabitants petitioned James I. for a reduction of taxes, as 300 acres of land, and all their houses, save fourteen, had then been destroyed by the sea. Not one-half that number of acres now remains in the parish, and hills of blown sand, called 'Marrams' from the plant by which they are overgrown, now occupy the site of the houses

* East Coast between Thames and Wash, J. B. Redman, C.E., Proc. Inst. Civil Engineers, vol. xxiii. pp. 31–33, 1864.

† Taylor's Geology of East Norfolk, p. 32.

which were still extant in 1605. When I visited the spot in 1839, I found the tower of the church half buried in the dunes of sand, as represented in the drawing (fig. 50), and twenty-three years afterwards my friend the Rev. S. W. King made a sketch from nearly the same spot, which is given in fig. 51. In the interval the sand dunes, which are always moving inland, had considerably altered their position in reference to the tower, which after the storm of 1862 was

Fig. 51.

Eccles Tower as it appeared after the storm of November 1862, from a drawing by Rev. S. W. King, taken from nearly the same position as fig. 50.

seen as represented in fig. 51, on the sea-side, the waves having washed the foundations of the edifice.* The level of the base of the tower, and of the ruins of the nave and chancel of the church (see fig. 51) has now such a relation to high-water mark, that Mr. King naturally suggests that there must have been a subsidence of this part of the coast since the church was built. The precise date of its erection is unknown, but the upper or octagonal part of the tower is supposed to date from the 16th century, and this addition

* Mr. Redman has given us a view of Eccles Tower as seen by him in 1861, when it was nearly as much on the sea ward side of the dunes as in 1862.

would not have been made at that period had the site been considered as in danger from the encroachments of the sea.

Observations on the level of the foundations of buildings now within reach of the tide may hereafter lead us to an exact estimate of a change of level if there be one in progress, although, antecedently to experience, we might have anticipated that a wasting coast was less favourable than any other for ascertaining whether the land was rising, sinking, or stationary. As the tide rises eight feet at Lowestoft, and sixteen at Cromer, it becomes a question whether in the course of four or five centuries its mean level at any given point on this eastern coast may vary sufficiently to explain the present position of the ruined church at Eccles relatively to high-water mark, but I am not aware that we have any recorded data for confirming or invalidating such an hypothesis.

M. E. de Beaumont has suggested that sand-dunes in Holland and other countries may serve as natural chronometers, by which the date of the existing continents may be ascertained. The sands, he says, are continually blown inland by the force of the winds, and by observing the rate of their march we may calculate the period when the movement commenced.* But the example just given will satisfy every geologist that we cannot ascertain the starting-point of dunes, all coasts being liable to waste, and the shores of the Low Countries in particular being not only exposed to inroads of the sea, but, as M. de Beaumont himself has well shown, having even in historical times undergone a change of level. The dunes may indeed, in some cases, be made use of as chronometers, to enable us to assign a minimum of antiquity to existing coast-lines; but this test must be applied with great caution, so variable is the rate at which the sands may advance into the interior.

Hills of blown sand, between Eccles and Winterton, have barred up and excluded the tide for many hundred years from the mouths of several small estuaries; but there are records of nine breaches, from 20 to 120 yards wide, having

* De Beaumont, Géologie Pratique, p. 218.

been made through these, by which immense damage was done to the low grounds in the interior. A few miles south of Happisburgh, also, are hills of blown sand, which extend to Yarmouth. These *dunes* afford a temporary protection to the coast, and an inland cliff about a mile long, at Winterton, shows clearly that at that point the sea must have penetrated formerly farther than at present.

Silting up of estuaries.—At Yarmouth, the sea has not advanced upon the sands in the slightest degree since the reign of Elizabeth. In the time of the Saxons, a great estuary extended as far as Norwich, which city is represented even in the thirteenth and fourteenth centuries, as 'situated on the banks of an arm of the sea.' The sands whereon Yarmouth is built first became firm and habitable ground about the year 1008, from which time a line of dunes has gradually increased in height and breadth stretching across the whole entrance of the ancient estuary, and obstructing the ingress of the tides so completely that they are only admitted by the narrow passage which the river keeps open, and which has gradually shifted several miles to the south. The ordinary tides at the river's mouth rise, at present, only to the height of three or four feet, the spring tides to about eight or nine.

By the exclusion of the sea, thousands of acres in the interior have become cultivated lands; and, exclusive of smaller pools, upwards of sixty freshwater lakes have been formed, varying in depth from fifteen to thirty feet, and in extent from one acre to twelve hundred.* The Yare, and other rivers, frequently communicate with these sheets of water; and thus they are liable to be filled up gradually with lacustrine and fluviatile deposits, and to be converted into land covered with forests. Yet it must not be imagined that the acquisition of new land fit for cultivation in Norfolk and Suffolk indicates any permanent growth of the eastern limits of our island to compensate its reiterated losses. No *delta* can form on such a shore.

In the sea immediately off Yarmouth is a great range of

* Taylor's Geology of East Norfolk, p. 10.

sand-banks parallel to the shore, the shape of which varies slowly from year to year, and often suddenly after great storms. Captain Hewitt, R.N., found in these banks, in 1836, a broad channel sixty-five feet deep, where there was only a depth of four feet during a prior survey in 1822. The sea had excavated to the depth of sixty feet in the course of fourteen years, or perhaps a shorter period. The new channel thus formed served in 1838 for the entrance of ships into Yarmouth Roads; and the magnitude of this change shows how easily a new set of the waves and currents might cause the submergence of the land gained within the ancient estuary of the Yare.

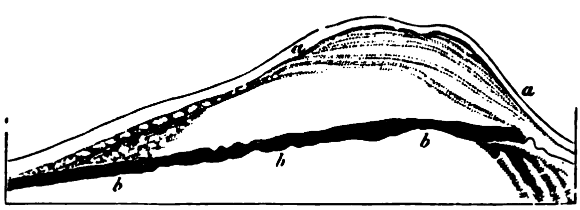
That great banks should be thrown across the mouth of estuaries on our eastern coast, where there is not a large body of river-water to maintain an open channel, is perfectly intelligible, when we bear in mind that the marine current, sweeping along the coast, is charged with the materials of wasting cliffs, and ready to form a bar anywhere the instant its course is interrupted or checked by any opposing stream. The mouth of the Yare has been, within the last five centuries, diverted about four miles to the south. In like manner it is evident that, at some remote period, the river Alde entered the sea at Aldborough, until its ancient outlet was barred up and at length transferred to a point no less than ten miles distant to the south-west. In this case, ridges of sand and shingle, like those of Lowestoft Ness, which will be described by-and-by, have been thrown up between the river and the sea; and the ancient sea-cliff is now to be seen inland. (See fig. 52.)

It may be asked why the rivers on our east coast are always deflected southwards, although the tidal current flows alternately from the south and north? The cause is to be found in the superior force of what is commonly called 'the flood tide from the north,' a tidal wave derived from the Atlantic, a small part of which passes eastward up the English Channel, and through the Straits of Dover and then northwards, while the principal body of water, moving much more rapidly in a more open sea, on the western side of Britain, first passes

the Orkneys, and then, turning, flows down between Norway and Scotland, and sweeps with great velocity along our eastern coast. It is well known that the highest tides on this coast are occasioned by a powerful north-west wind, which raises the eastern part of the Atlantic, and causes it to pour a greater volume of water into the German Ocean. This circumstance of a violent *off-shore* wind being attended with a rise of the waters, instead of a general retreat of the sea, naturally excites the wonder of the inhabitants of our coast. In many districts they look with confidence for a rich harvest of that valuable manure, the sea-weed, when the north-westerly gales prevail, and are rarely disappointed.

Coast of Suffolk.—The cliffs of Suffolk, to which we next

Fig. 52.



Map of Lowestoft Ness, Suffolk.*

a, a. The dotted lines express a series of sand and shingle, forming the extremity of the triangular space called the Ness.
b, b, b. The dark line represents the inland cliff on which the town of Lowestoft stands, between which and the sea is the Ness.

proceed, are somewhat less elevated than those of Norfolk, but composed of similar alternations of clay, sand, and gravel. From Gorleston in Suffolk, to within a few miles north of Lowestoft, the cliffs are being slowly undermined. Near the last-mentioned town there is an inland cliff about sixty feet high, the sloping talus of which is covered with turf and heath. Between the cliff and the sea is a low flat tract of sand, called the Ness, nearly three miles long, and for the most part out of reach of the highest tides (see fig. 52). The point

* From Mr. R. C. Taylor's Mem., see Phil. Mag., Oct. 1827, p. 297.

of the Ness projects from the base of the original cliff to the distance of 660 yards. This accession of land, says Mr. Taylor, has been effected at distinct and distant intervals, by the influence of currents running between the land and a shoal called the Holm Sand about a mile off Lowestoft. The lines of growth in the Ness are indicated by a series of concentric ridges or banks enclosing limited areas, and several of these ridges have been formed within the observation of persons now living. A rampart of heavy materials is first thrown up to an unusual altitude by some extraordinary tide, attended with a violent gale. Subsequent tides extend the base of this high bank of shingle, and the interstices are then filled with sand blown from the beach. The Arundo and other sea-side plants by degrees obtain a footing; and creeping along the ridge, give solidity to the mass, and form in some cases a matted covering of turf. Meanwhile another mound is forming externally, which by the like process rises and gives protection to the first. If the sea forces its way through one of the external and incomplete mounds, the breach is soon repaired. After awhile the maritime plants within the areas enclosed by these embankments are succeeded by a better species of herbage affording good pasturage, and the sands become sufficiently firm to support buildings.

Destruction of Dunwich by the sea.—Of the gradual destruction of Dunwich, once the most considerable seaport on this coast, we have many authentic records. Gardner, in his history of that borough, published in 1754, shows, by reference to documents, beginning with Doomsday Book, that the cliffs at Dunwich, Southwold, Easton, and Pakefield, have been always subject to waste. At Dunwich, in particular, two tracts of land which had been taxed in the eleventh century, in the time of King Edward the Confessor, are mentioned, in the Conqueror's survey, made but a few years afterwards, as having been devoured by the sea. The losses, at a subsequent period, of a monastery,—at another of several churches,—afterwards of the old port,—then of four hundred houses at once,—of the church of St. Leonard, the high-road, town-hall, gaol, and many other buildings,

are mentioned, with the dates when they perished. It is stated that, in the sixteenth century, not one quarter of the town was left standing; yet, the inhabitants retreating inland, the name was preserved, as has been the case with many other ports when their ancient site has been blotted out. There is, however, a church, of considerable antiquity, still standing, the last of twelve mentioned in some records. In 1740, the laying open of the churchyard of St. Nicholas and St. Francis, in the sea-cliffs, is well described by Gardner, with the coffins and skeletons exposed to view—some lying on the beach, and rocked

> In cradle of the rude imperious surge.

Of these cemeteries no remains can now be seen. Ray also says, 'that ancient writings make mention of a wood a mile and a half to the east of Dunwich, the site of which must at present be so far within the sea.'* This city, once so flourishing and populous, is now a small village, with about twenty houses and one hundred inhabitants.

There is an old tradition, 'that the tailors sat in their shops at Dunwich, and saw the ships in Yarmouth Bay;' but when we consider how far the coast at Lowestoft Ness projects between these places, we cannot give credit to the tale, which, nevertheless, proves how much the inroads of the sea in times of old had prompted men of lively imagination to indulge their taste for the marvellous.

Gardner's description of the cemeteries laid open by the waves reminds us of the scene which has been so well depicted by Bewick,† and of which numerous points on the same coast might have suggested the idea. On the verge of a cliff, which the sea has undermined, are represented the unshaken tower and western end of an abbey. The eastern aisle is gone, and the pillars of the cloister are soon to follow. The waves have almost isolated the promontory, and invaded the cemetery, where they have made sport with the mortal relics, and thrown up a skull upon the beach. In the foreground is seen a broken tombstone, erected, as its legend

* Consequences of the Deluge, Phys. Theol. Discourses.

† History of British Birds, vol. ii. p 220, ed. 1821.

tells, 'to *perpetuate* the memory'—of one whose name is obliterated, as is that of the county for which he was 'Custos Rotulorum.' A cormorant is perched on the monument, defiling it, as if to remind some moralizer, like Hamlet, of 'the base uses' to which things sacred may be turned. Had this excellent artist desired to satirize certain popular theories of geology, he might have inscribed the stone to the memory of some philosopher who taught 'the permanency of existing continents'—'the era of repose'—'the impotence of modern causes.'

The incursions of the sea at Aldborough were formerly very destructive, and this borough is known to have been once situated a quarter of a mile east of the present shore. The inhabitants continued to build farther inland, till they arrived at the extremity of their property, and then the town decayed greatly; but two sand-banks, thrown up at a short distance, now afford a temporary safeguard to the coast. Between these banks and the present shore, where the current now flows, the sea is twenty-four feet deep on the spot where the town formerly stood.

Essex.—Harwich is said to have owed its rise to the destruction of Orwell, a town which stood on the spot now called 'the west rocks,' and was overwhelmed by an inroad of the sea since the Conquest. Apprehensions have been entertained that the isthmus on which Harwich stands may at no remote period become an island, for the sea may be expected to make a breach near Lower Dovercourt, where Beacon Cliff is composed of horizontal beds of London clay containing septaria. It had wasted away considerably between the years 1829 and 1838, at both which periods I examined this coast. In that short interval several gardens and many houses had been swept into the sea, and in April 1838 a whole street was threatened with destruction. The advance of the sea is much accelerated by the traffic carried on in septaria, which are shipped off for cement as fast as they fall down upon the beach. These stones, if allowed to remain in heaps on the shore, would break the force of the waves, and retard the conversion of the peninsula into an island, an event which might be followed by the destruction

of the town of Harwich. Captain Washington, R.N., ascertained in 1847, that Beacon Cliff above mentioned, which is about fifty feet high, had given way at the rate of forty feet in forty-seven years, between 1709 and 1756; eighty feet between 1756 and 1804; and three hundred and fifty feet between the latter period and 1841; showing a rapidly accelerated rate of destruction.*

Among other losses it is recorded that, since the year 1807, a field called the Vicar's Field, which belonged to the living of Harwich, has been overwhelmed; † and in the year 1820 there was a considerable space between the battery at Harwich, built in the beginning of the present century, and the sea; part of the fortification had been swept away in 1829, and the rest then overhung the water.

At Walton-on-the-Naze, in the same county, the cliffs, composed of London clay, capped by the shelly sands of the crag, reach the height of about 100 feet, and are annually undermined by the waves. The old churchyard at Walton has been washed away, and the cliffs to the south are constantly disappearing.

Kent.—Isle of Sheppey.—On the coast bounding the estuary of the Thames, there are numerous examples both of the gain and loss of land. The Isle of Sheppey, which is now about six miles long by four in breadth, is composed of London clay. The cliffs on the north, which are from 100 to 200 feet high, decay rapidly, fifty acres having been lost in twenty years, between 1810 and 1830. The church at Minster, now near the coast, is said to have been in the middle of the island in 1780; and if the present rate of destruction should continue, we might calculate the period, and that not a very remote one, when the whole island will be annihilated. On the coast of the mainland to the east of Sheppey is Herne Bay; a place still retaining the name of a bay, although the term is no longer appropriate, as the waves and currents have swept away the ancient headlands. There was formerly a small promontory in the line of the shoals where the present

* Tidal Harbour Commissioners' First Report, 1845, p. 176.

† On the authority of Dr. Mitchell, F.G.S.

pier is built, by which the larger bay was divided into two called the Upper and Lower.*

Still farther east stands the church of Reculver, upon a cliff, about twenty-five feet high, composed of sand with some interstratified slabs of clayey sandstone. Reculver (Regulvium) was an important military station in the time of the Romans, and appears, from Leland's account, to have been, so late as Henry VIII.'s reign, nearly one mile distant from the sea. In the 'Gentleman's Magazine' there is a view of it, taken in 1781, which still represents a considerable space as inter-

Fig. 53.

View of Reculver Church, taken in the year 1781.

1. Isle of Sheppey. 2. Ancient chapel now destroyed. The cottage between this chapel and the cliff was demolished by the sea in 1782.

vening between the north wall of the churchyard and the cliff.† Some time before the year 1780, the waves had reached the site of the ancient Roman camp, or fortification, the walls of which had continued for several years after they were undermined to overhang the sea, being firmly cemented into one mass. They were eighty yards nearer the sea than the church, and they are spoken of in the 'Topographica Britannica,' in the year 1780, as having recently fallen down. In 1804, part of the churchyard with some adjoining houses was washed away, and the ancient church, with its two spires, was

* On the authority of W. Gunnel, Esq., and W. Richardson, Esq., F.G.S.
† Vol. ii. New Ser. 1809, p. 801.

dismantled and abandoned as a place of worship, but kept in repair as a landmark well known to mariners. I visited the spot in June 1851, and saw human bones and part of a wooden coffin projecting from the cliff, near the top. The whole building would probably have been swept away long ere this, had not the force of the waves been checked by an artificial causeway of stones and large wooden piles driven into the sands on the beach to break the force of the waves.

Isle of Thanet.—The Isle of Thanet was, in the time of the

Fig. 54.

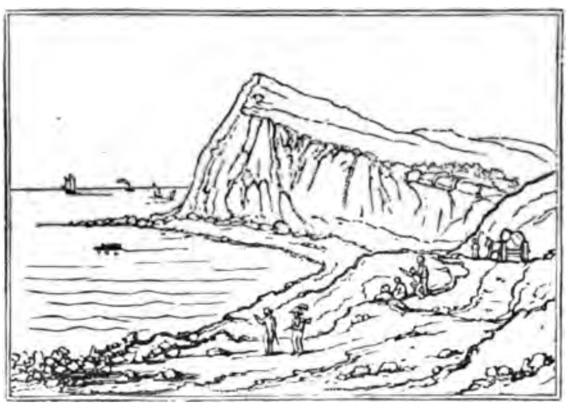
Reculver Church, in 1834.

Romans, separated from the rest of Kent by a navigable channel, through which the Roman fleets sailed on their way to and from London. Bede describes this small estuary as being, in the beginning of the eighth century, three furlongs in breadth; and it is supposed that it began to grow shallow about the period of the Norman Conquest. It was so far silted up in the year 1845 that an Act was obtained to build a bridge across it; and it has since become marsh land with small streams running through it. On the coast, Bedlam

Farm, belonging to the hospital of that name, lost eight acres in the twenty years preceding 1830, the land being composed of chalk from forty to fifty feet above the level of the sea. It has been computed, that the average waste of the cliff between the North Foreland and the Reculvers, a distance of about eleven miles, is not less than two feet per annum. The chalk cliffs on the south of Thanet, between Ramsgate and Pegwell Bay, had on an average lost three feet per annum during the ten years preceding 1830.

Goodwin Sands.—The Goodwin Sands lie opposite this part of the Kentish coast. They are about ten miles in length, and are in some parts three, and in others seven, miles dis-

Fig. 55.



Shakspeare's Cliff in 1836, seen from the north-east.

tant from the shore; and for a certain space, are laid bare at low water. That they are a remnant of land, and not 'a mere accumulation of sea sand,' as Rennel imagined,* may be presumed from the fact that, when the erection of a lighthouse on this shoal was in contemplation by the Trinity Board in the year 1817, it was found, by borings, that the bank consisted of fifteen feet of sand, resting on blue clay; and, by subsequent borings, the subjacent chalk has been reached. An obscure tradition has come down to us, that the estates of Earl Goodwin, the father of Harold, who died in the year 1053, were situated here, and some have

* Geog. of Herod. vol. ii. p. 326.

conjectured that they were overwhelmed by the flood mentioned in the Saxon chronicle, *sub anno* 1099. The last remains of an island, consisting, like Sheppey, of clay, may perhaps have been carried away about that time.

There are other records of waste in the county of Kent, as at Deal; and at Dover, where Shakspeare's Cliff, composed entirely of chalk, has suffered greatly, and continually diminishes in height, the slope of the hill being towards the land. (See fig. 55.) There was an immense landslip from this cliff in 1810, by which Dover was shaken as if by an earthquake, and a still greater one in 1772.* We may suppose, therefore, that the view from the top of the precipice in the year 1600, when the tragedy of King Lear was written, was more 'fearful and dizzy' than it is now. The best antiquarian authorities are agreed, that Dover Harbour was formerly an estuary, the sea flowing up a valley between the chalk hills. The remains found in different excavations confirm the description of the spot given by Cæsar and Antoninus, and there is clear historical evidence to prove that at an early period there was no shingle at all at Dover.†

Straits of Dover.—In proceeding from the northern parts of the German Ocean towards the Straits of Dover, the water becomes gradually more shallow, so that in the distance of about two hundred leagues, we pass from a depth of 120 fathoms to that of 58, 38, 18, and at one point near the middle of the Channel even less than 2 fathoms. The shallowest part follows a line drawn between Romney Marsh and Boulogne. From this point the English Channel again deepens progressively as we proceed westward, so that the Straits of Dover may be said to part two seas.‡

Whether England was formerly united to France has often been a favourite subject of speculation. So early as 1605 our countryman Verstegan, in his 'Antiquities of the English Nation,' observed that many preceding writers had maintained this opinion, but without supporting it by any weighty reasons. He accordingly endeavours himself to confirm it by

* Dodsley's Ann. Regist. 1772.

† See J. B. Redman on Changes of S.E. Coast of England, Proceed. Instit. Civil Engin. vol. xi. 1851, 1852.

‡ Stevenson, Ed. Phil. Journ. No. v. p. 45, and Dr. Fitton, Geol. Trans 2d series, vol. iv. plate 9.

various arguments, the principal of which are, first, the proximity and identity of the composition of the opposite cliffs and shores of Albion and Gallia, which, whether flat and sandy, or steep and chalky, correspond exactly with each other; secondly, the occurrence of a submarine ridge, called 'Our Lady's Sand,' extending from shore to shore at no great depth, and which from its composition appears to be the original basis of the isthmus; thirdly, the identity of the noxious animals in France and England, which could neither have swum across, nor have been introduced by man. Thus no one, he says, would have imported wolves, therefore 'these wicked beasts did of themselves pass over.' He supposes the ancient isthmus to have been about six English miles in breadth, composed entirely of chalk and flint, and in some places of no great height above the sea-level. The operation of the waves and tides, he says, would have been more powerful when the straits were narrower, and even now they are destroying cliffs composed of similar materials. He suggests the possible co-operation of earthquakes; and when we consider how many submarine forests skirt the southern and eastern shores of England, and that there are raised beaches at many points above the sea-level, containing fossil shells of recent species, it seems reasonable to suppose that such upward and downward movements, taking place perhaps as slowly as those now in progress in Sweden and Greenland, may have greatly assisted the denuding force of 'the ocean stream,' *Ποταμοιο μεγα σθενος Ωκεανοιο.*

Folkestone.—At Folkestone, the sea undermines the chalk and subjacent strata. About the year 1716 there was a remarkable sinking of a tract of land near the sea, so that houses became visible from certain points at sea, and from particular spots on the sea cliffs, from whence they could not be seen previously. In the description of this subsidence in the Phil. Trans. 1716, it is said, 'that the land consisted of a solid stony mass (chalk), resting on wet clay (gault), so that it slid forwards towards the sea, just as a ship is launched on tallowed planks.' It is also stated that, within the memory of persons then living, the cliff there had been washed away to the extent of ten rods.

Encroachments of the sea at Hythe are also on record; but between this point and Rye there has been a gain of land within the times of history; the rich level tract called Romney Marsh, or Dungeness, about ten miles in width and five in breadth, and formed of silt, having received great accession. Mr. Redman has cited numerous old charts and trustworthy authorities to prove that the average annual increase of the promontory amounted for two centuries, previous to 1844, to nearly six yards. Its progress, however, has fluctuated during that period; for between 1689 and 1794, a term of 105 years, the rate was as much as 8½ yards per annum. He observes 'that this great accumulation, commonly called Romney Marsh, is composed for a distance of about two miles of undulating ridges marking the periodical accessions made to the coast, like the rings of growth in timber.'* It is ascertained that the shingle is derived from the westward. Whether the pebbles are stopped by the meeting of the tide from the north flowing through the Straits of Dover, with that which comes up the Channel from the west, as was formerly held, or by the check given to the tidal current by the waters of the Rother, as some maintain, is still a disputed question. There is, however, no doubt that since the Point of Dungeness has advanced, forming a great natural groin, it intercepts the shingle which formerly travelled eastward and was accumulated by artificial groins at Hythe. The martello towers erected on the low coast S. and SW. of Hythe must ere long perish, as Mr. Mackeson has pointed out to me, for want of a supply of protecting shingle. At Lymchurch the towers numbered 26, 27, have already been removed, their destruction being threatened by the advancing tide. The town of Winchelsea, situated to the south of Romney Marsh, was destroyed in the reign of Edward I., the mouth of the Rother stopped up, and the river diverted into another channel. In its old bed, an ancient vessel, apparently a Dutch merchantman, was found about the year 1824. It was built entirely of oak, and much blackened.† Large quantities of hazel-nuts, peat, and wood are found in digging in Romney Marsh.

* Redman, Proc. Civil Engin. vol. xi. p. 169.

† Edin. Journ. of Science, No. xix. p. 56.

South coast of England.—Westward of Hastings, or of St. Leonard's, the shore-line has been giving way as far as Pevensey Bay, where formerly there existed a haven now entirely blocked up by shingle. The waste has amounted for a series of years to seven feet per annum in some places, and several martello towers had in consequence, before 1851, been removed by the Ordnance.* At the promontory of Beachy Head a mass of chalk, three hundred feet in length, and from seventy to eighty in breadth, fell in the year 1813 with a tremendous crash; and similar slips have since been frequent.†

About a mile to the west of the town of Newhaven, the remains of an ancient entrenchment are seen on the brow of Castle Hill. This earthwork, supposed to be British, was evidently once of considerable extent and of an oval form, but the greater part has been cut away by the sea. The cliffs, which are undermined here, are high; more than one hundred feet of chalk being covered by tertiary clay and sand, from sixty to seventy feet in thickness. In a few centuries the last vestiges of the Woolwich Beds or plastic clay formation on the southern borders of the chalk of the South Downs on this coast will probably be annihilated, and future geologists will learn, from historical documents only, the ancient geographical boundaries of this group of strata in that direction. On the opposite side of the estuary of the Ouse, on the east of Newhaven harbour, a bed of shingle, composed of chalk flints derived from the waste of the adjoining cliffs, had accumulated at Seaford for several centuries. In the great storm of November 1824, this bank was entirely swept away, and the town of Seaford inundated. Another great beach of shingle is now forming from fresh materials.

The whole coast of Sussex has been incessantly encroached upon by the sea from time immemorial; besides the camp at Newhaven, two ancient earthworks of unknown date, one near Seaford, and the other near Eastbourne, have been partially destroyed by the encroachments of the sea. Although sudden inundations only, which overwhelmed fertile or inhabited tracts, are noticed in history, the records attest an extraor-

* Redman, as cited, p. 315.

† Webster, Geol. Trans. vol. ii. p. 192, 1st series.

dinary amount of loss. During a period of no more than eighty years, there are notices of about *twenty* inroads, in which tracts of land of from twenty to *four hundred acres* in extent were overwhelmed at once, the value of the tithes being mentioned in the Taxatio Ecclesiastica.* In the reign of Elizabeth, the town of Brighton was situated on that tract where the chain pier now extends into the sea. In the year 1665 twenty-two tenements had been destroyed under the cliff. At that period there still remained under the cliff 113 tenements, the whole of which were overwhelmed in 1703 and 1705. No traces of the ancient town are now perceptible, yet there is evidence that the sea has merely resumed its ancient position at the base of the cliffs, the site of the old town having been nothing more than a beach abandoned by the ocean for ages.

Hampshire.—Isle of Wight.—It would be endless to allude to all the localities on the Sussex and Hampshire coasts where the land has given way; but I may point out the relation which the geological structure of the Isle of Wight bears to its present shape, as attesting that the coast owes its outline to the continued action of the sea. Through the middle of the island runs a high ridge of chalk strata, in a vertical position, and in a direction east and west. This chalk forms the projecting promontory of Culver Cliff on the east, and of the Needles on the west; while Sandown Bay on the one side, and Compton Bay on the other, have been hollowed out of the softer sands and argillaceous strata, which are inferior, in geological position, to the chalk.

The same phenomena are repeated in the Isle of Purbeck, where the line of vertical chalk forms the projecting promontory of Handfast Point; and Swanage Bay marks the deep excavation made by the waves in the softer strata, corresponding to those of Sandown Bay.

Hurst Castle bank—progressive motion of sea beaches.—Although the loose pebbles and grains of sand composing any given line of sea beach are carried sometimes one way, sometimes another, they have, nevertheless, an ultimate

* Mantell, Geology of Sussex, p. 293.

motion in one particular direction.* Their progress, for example, on the south coast of England, is from west to east, which is owing partly to the action of the waves driven eastwards by the prevailing wind, and partly to the current, or the motion of the general body of water caused by the tides and winds. The force of the waves gives motion to pebbles which the velocity of the currents alone would be unable to carry forwards; but as the pebbles are finally reduced to sand or mud, by continual attrition, they are brought within the influence of a current; and this cause must determine the course which the main body of matter derived from wasting cliffs will eventually take.

It appears, from the observations of Mr. Palmer and others, that if a pier or groin be erected anywhere on our southern or south-eastern coast to stop the progress of the beach, a heap of shingle soon collects on the western side of such artificial barriers. The pebbles continue to accumulate till they rise as high as the pier or groin, after which they pour over in great numbers during heavy gales.†

The western entrance of the Solent, a channel dividing the Isle of Wight from the mainland, is crossed for more than two-thirds of its width by the shingle-bank of Hurst Castle, which is about two miles long, seventy yards broad, and twelve feet high, presenting an inclined plane to the west. This singular bar consists of a bed of rounded chalk flints, resting on a submarine argillaceous base. The flints and a few other pebbles, intermixed, are derived from the waste of Hordwell, and other cliffs to the westward, where tertiary strata, capped with a covering of broken chalk flints, from five to fifty feet thick, are rapidly undermined. In the great storm of November 1824, this bank of shingle was moved bodily forwards for forty yards towards the north-east; and certain piles, which served to mark the boundaries of two manors, were found after the storm on the opposite side of the bar. At the same time many acres of pasture land

* See Palmer on Shingle Beaches, Phil. Trans. 1834, p. 568.

† Groins are formed of piles and wooden planks, or of faggots staked down; and are used either to break the force of the waves, or to retain the beach.

were covered by shingle, on the farm of Westover, near Lymington. But the bar was soon restored to its old position by pebbles drifted from the west; and it appears from ancient maps that it has preserved the same general outline and position for centuries.*

Mr. Austen remarks that, as a general rule, it is only when high tides concur with a gale of wind, that the sea reaches the base of cliffs so as to undermine them. But the waves are perpetually employed in abrading and fashioning the materials already strewed over the beach. Much of the gravel and shingle is always travelling up and down, between high-water mark and a slight depth below the level of the lowest tides, and occasionally the materials are swept away and carried into deeper water. Owing to these movements, every portion of our southern coast may be seen at one time or other in the condition of bare rock. Yet other beds of sand and shingle soon collect, and, although composed of new materials, invariably exhibit on the same spots precisely similar characters.†

The cliffs between Hurst Shingle Bar and Christchurch are undermined continually, the sea having often encroached for a series of years at the rate of a yard annually. Within the memory of persons now living, it has been necessary thrice to remove the coast-road farther inland. The tradition, therefore, is probably true, that the church of Hordwell was once in the middle of that parish, although now (1830) very near the sea. The promontory of Christchurch (Hengistbury) Head gives way slowly. It is the only point between Lymington and Poole Harbour, in Dorsetshire, where any hard stony masses occur in the cliffs. Five layers of large ferruginous concretions, somewhat like the septaria of the London clay, have occasioned a resistance at this point, to which we may ascribe this headland. In the meantime, the waves have cut deeply into the soft sands and loam of Poole Bay; and after severe frosts, great landslips take place, which by degrees become enlarged into narrow ravines, or chines, as they are called, with vertical sides. One of these

* Redman, as cited, p. 315.

† Rob. A. C. Godwin-Austen on the Valley of the English Channel, Quart. Journ. G. S. vol. vi. p. 72.

chines, near Boscomb, has been deepened twenty feet within a few years (1830). At the head of each there is a spring, the waters of which have been chiefly instrumental in producing these narrow excavations, which are sometimes from 100 to 150 feet deep.

Isle of Portland.—The peninsulas of Purbeck and Portland are continually wasting away. In the latter, the soft argillaceous substratum (Kimmeridge clay) hastens the dilapidation of the superincumbent mass of limestone.

In 1665 the cliffs adjoining the principal quarries in Portland gave way to the extent of one hundred yards, and fell into the sea; and in December 1734, a slide to the extent of 150 yards occurred on the east side of the isle. But a much more memorable occurrence of this nature, in 1792, occasioned probably by the undermining of the cliffs, is thus described in Hutchin's History of Dorsetshire:—'Early in the morning the road was observed to crack: this continued increasing, and before two o'clock the ground had sunk several feet, and was in one continued motion, but attended with no other noise than what was occasioned by the separation of the roots and brambles, and now and then a falling rock. At night it seemed to stop a little, but soon moved again; and, before morning, the ground from the top of the cliff to the water-side had sunk in some places fifty feet perpendicular. The extent of ground that moved was about *a mile and a quarter* from north to south, and 600 yards from east to west.'

Formation of the Chesil Bank.—Portland is connected with the mainland by the Chesil Bank, a ridge of shingle about fifteen miles long, the first part of which, near Portland, for a length of about two miles, has the sea on each side of it. It then continues seven miles farther in a north-westerly direction as far as Abbotsbury, sloping steeply on the one side towards the sea, and on the other towards a narrow channel called the Fleet, which may be regarded as an estuary the waters of which are brackish. It then stretches for five miles farther as a pebbly beach thrown against the coast of Dorsetshire.

The pebbles forming this immense barrier are chiefly

siliceous, all loosely thrown together, and rising to the height of from twenty to thirty feet above the ordinary high-water mark; and forty feet at the south-eastern end, which is nearest the Isle of Portland, where the pebbles are largest. Here its width is about 600 feet, which diminishes to about 500 at Abbotsbury.

That part of the bar which attaches Portland to the mainland rests on Kimmeridge clay, which is sometimes exposed to view during storms. The clay may have formed a shoal, and the set of the tides in the narrow channel may have arrested the course of the pebbles, which are always coming from the west. It is a singular fact, that, throughout the Chesil Bank, the pebbles increase gradually in size as we proceed south-eastward, or as we go farther from the quarter which supplied them. Had the case been reversed, we should naturally have attributed the circumstance to the constant wearing down of the pebbles by friction, the beach along which they are rolled being seventeen miles in length. But the true explanation of the phenomenon is doubtless this: the strongest currents or movements of the sea during storms, when a gale from the south-west co-operates with the tide, act with greater power in the more open channel or farthest from the head of the bay; within the bay the land affords more shelter from the wind and waves. In other words, the force of the sea increases southwards, and as the direction of the bank is from north-west to south-east, the size of the masses coming from the westward and thrown ashore must always be largest where the motion of the waves and currents is most violent. Colonel Reid states that all calcareous stones rolled along from the west are soon ground into sand, and in this form they pass round Portland Island.*

The storm of 1824 burst over the Chesil Bank with great fury, and the village of Chesilton, built upon its southern extremity, was overwhelmed, with many of the inhabitants. During another gale on the 23rd Nov. 1852, the south-west wind threw in upon the bank during the night and early part of the following day a mass of shingle amounting by

* See Palmer on Motion of Shingle Beaches, Phil. Trans. 1834, p. 568; and Col. Sir W. Reid, Papers of Royal Engineers, 1838, vol. ii. p. 128.

measurement, according to Mr. Coode, C.E., to no less than three and a half millions of tons.*

The storm before alluded to of 1824 carried away part of the Breakwater at Plymouth, and huge masses of rock, from two to five tons in weight, were lifted from the bottom of the weather side, and rolled fairly to the top of the pile. One block of limestone, weighing seven tons, was washed round the western extremity of the Breakwater, and carried 150 feet.† The propelling power is derived in these cases from the breaking of the waves, which run fastest in shallow water, and for a short space far exceed the most rapid currents in swiftness. It was in the same month, and also during a spring-tide, that a great flood is mentioned on the coasts of England, in the year 1099. Florence of Worcester says, 'On the third day of the nones of Nov. 1099, the sea came out upon the shore and buried towns and men very many, and oxen and sheep innumerable.' We also read in the Saxon Chronicle, for the year 1099, 'This year eke on St. Martin's mass day, the 11th of Novembre, sprung up so much of the sea flood, and so myckle harm did, as no man minded that it ever afore did, and there was the ylk day a new moon.'

South of the Bill, or southern point of Portland, is a remarkable shoal in the channel at the depth of seven fathoms, called 'the Shambles,' consisting entirely of rolled and broken shells of *Purpura lapillus*, *Mytilus edulis*, and other species now living. This mass of light materials is always in motion, varying in height from day to day, and yet the shoal remains constant.

Dorsetshire—Devonshire.—At Lyme Regis, in Dorsetshire, the 'Church Cliffs,' as they are called, consisting of lias about one hundred feet in height, gradually fell away at the rate of one yard a year, from 1800 to 1829.‡

An extraordinary landslip occurred on the 24th of December, 1839, on the coast in Devonshire between Lyme Regis and Axmouth, which has been described by the Rev. W. D. Conybeare, to whose kindness I am indebted

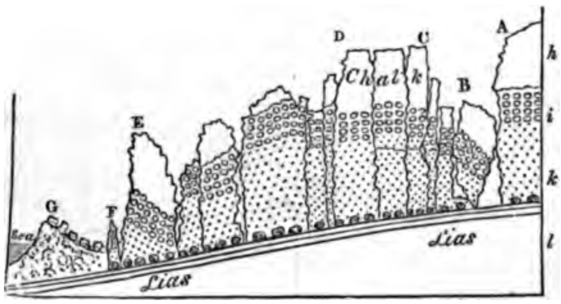
* Coode, Proc. Inst. of Civ. Engineers, 1852-3, vol. xii. p. 545.

† De la Beche, Geological Manual, p. 82.

‡ According to the measurement of Carpent of Lyme.

for the accompanying section, fig. 56. The tract of downs ranging there along the coast is capped by chalk (*h*), which rests on sandstone, alternating with chert (*i*), beneath which is more than 100 feet of loose sand (*k*), with concretions at the bottom, and belonging, like *i*, to the upper green-sand formation or chloritic series; the whole of the above masses, *h*, *i*, *k*, repose on retentive beds of clay (*l*), belonging to the lias, which shelves towards the sea. Numerous springs issuing from the loose sand (*k*) have gradually removed portions of it, and thus undermined the superstratum, so as to have caused subsidences at former times,

Fig. 56.



Landslip, near Axmouth, Dec. 1839. (Rev. W. D. Conybeare.)

A. Tract of Downs still remaining at their original level.
B. New ravine.
C, D. Sunk and fractured strip united to A, before the convulsion.
D, E. Bendon undercliff as before, but more fissured, and thrust forward about fifty feet toward the sea.
F. Pyramidal crag, sunk from seventy to twenty feet in height.
G. New reef upheaved from the sea.

and to have produced a line of undercliff between D and E. In 1839 an excessively wet season had saturated all the rocks with moisture, so as to increase the weight of the incumbent mass, from which the support had already been withdrawn by the action of springs. Thus the superstrata were precipitated into hollows prepared for them, and the adjacent masses of partially undermined rock, to which the movement was communicated, were made to slide down on a slippery basis of watery sand towards the sea. These causes

gave rise to a convulsion, which began on the morning of the 24th of December, with a crashing noise; and, on the evening of the same day, fissures were seen opening in the ground, and the walls of tenements rending and sinking, until a deep chasm or ravine, B, was formed extending nearly three quarters of a mile in length, with a depth of from 100 to 150 feet, and a breadth exceeding 240 feet. At the bottom of this deep gulf lie fragments of the original surface thrown together in the wildest confusion. In consequence of lateral movements, the tract intervening between

Fig. 57.

View of the Axmouth landslip from Great Bindon, looking westward to the Sidmouth hills, and estuary of the Exe. From an original drawing by Mrs. Buckland.

the new fissure and the sea, including the ancient undercliff, was fractured, and the whole line of sea-cliff carried bodily forwards for many yards. 'A remarkable pyramidal crag, F, off Culverhole Point, which lately formed a distinguishing landmark, has sunk from a height of about seventy to twenty feet, and the main cliff, E, previously more than fifty feet distant from this insulated crag, is now brought almost close to it.' This motion of the sea-cliff has produced a farther effect, which may rank among the most striking phenomena

of this catastrophe. The lateral pressure of the descending rocks has urged the neighbouring strata, extending beneath the shingle of the shore, by their state of unnatural condensation, to burst upwards in a line parallel to the coast—thus an elevated ridge, G, more than a mile in length, and rising more than forty feet, covered by a confused assemblage of broken strata, and immense blocks of rock, invested with sea-weed and corallines, and scattered over with shells and star-fish, and other productions of the deep, forms an extended reef in front of the present range of cliffs.' *

A full account of this remarkable landslip, with a plan, sections, and many fine illustrative drawings, was published by Messrs. Conybeare and Buckland,† from one of which the fig. 57 has been reduced.

Tor Bay.—The shores which bound Tor Bay give way continually at many points: their waste forms the subject of a memoir published by Mr. Pengelly, in 1861.‡ He has shown that thrice in the course of the last hundred years it has been necessary to carry the road between Torquay and Paignton farther inland. A solid mass of masonry, built for the protection of the present road, was swept away by the waves in a storm, in October 1859, at which time the neighbouring cliffs were also undermined at many points on the coast, comprising some precipitous rocks of limestone.

St. Michael's Mount, Cornwall.—When we reflect on the great amount of change caused by the undermining power of the waves, and by landslips in the last three or four centuries on our southern coasts, and the proofs of submergence of numerous forests which have sunk at some unknown period, and which extend here and there from the shore line to some distance out at sea; it becomes a matter of surprise that we should find a single point where the outline of the present coast can be demonstrated to have remained for nineteen centuries unaltered. For this reason St. Michael's Mount in Cornwall deserves our special attention, for it can be shown that all the characteristic features in its physical

* Rev. W. D. Conybeare, letter dated Axminster, Dec. 21, 1839.

† London, J. Murray, 1840.

‡ Geologist, vol. iv. p. 447. 1861.

geography have been retained throughout that long series of centuries identically such as they now are.

The Mount (see figs. 58, 59, and 60, pp. 544 and 545) consists chiefly of granite, with some slate rock, like that of the adjoining coast. It is 195 feet high, with precipitous sides, and is situated near the head of Mount's Bay, which is distant about ten miles eastward from the Land's End. Twice in every twenty-four hours this mount is an island, and twice when the tide falls it is connected by a narrow isthmus with the mainland. This isthmus is composed of the slate before mentioned, the same which enters into the structure of part of the Mount, where it is penetrated by veins of granite at the junction of the two formations. At the highest spring tides there is no less than twelve feet of water on the isthmus, and six at neap tides: in ordinary weather it is usually dry for five hours at low tide. The annexed views (p. 545) will give the reader an idea of the appearance of the Mount at high and low water.*

As there is no other rock on our coast which is twice alternately an island and a promontory every twenty-four hours, this circumstance alone would be almost conclusive in favour of the opinion, that the Mount is the Ictis of Diodorus Siculus. That historian, writing in the year 9 B.C., thus speaks of the trade of the ancients with Britain:— 'The inhabitants of Belerium are hospitable, and, on account of their intercourse with strangers, civilised in their habits.' 'It is they who produce tin, which they melt into the form of astragali, and they carry it to an island in front of Britain, called Ictis. This island is left dry at low tides, and they then transport the tin in carts from the shore. Here the traders buy it from the natives, and carry it to Gaul, over which it travels on horseback in about thirty days, to the mouths of the Rhone.'

About the year 1823, a block of tin, now in the museum of the Royal Institute of Cornwall at Truro, was dredged up in Falmouth Harbour (see fig. 61). It has the form, says

* For the original of figs. 58, and 59, I am indebted to the kindness of Sir Henry James.

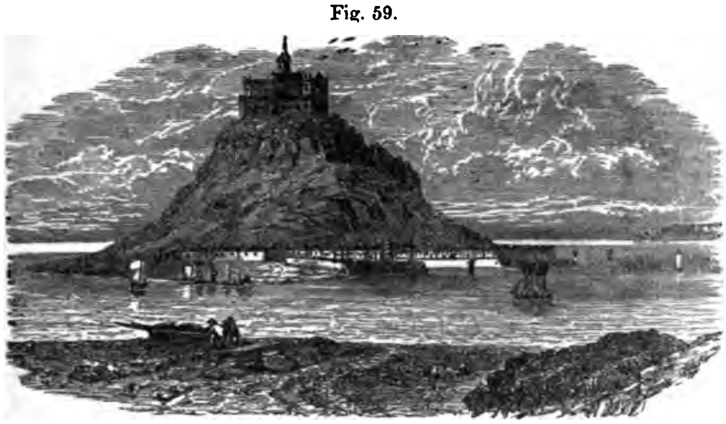
Sir H. James, which Diodorus might well have compared to an astragalus; one side slightly convex (see fig. 61), as if to

Fig. 58.

View of St. Michael's Mount at low tide.

enable it to fit the bottom of a boat, the whole being so shaped that it might be easily slung by cords on the side of a horse,

Fig. 59.



View of St. Michael's Mount at high tide.

and two of these balancing each other would constitute such a load as a horse might conveniently carry.* In addition to

* Col. Sir H. James on Block of Tin dredged up in Falmouth Harbour, 45th Ann. Report Royal Inst. Cornwall, 1863.

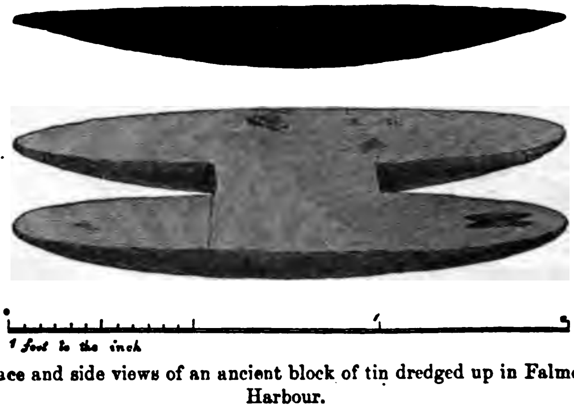
the above considerations, Dr. Barham has shown that the Ictis of Diodorus not only answers geographically to St. Michael's

Fig. 60.

View of St. Michael's Mount at high tide, showing the position of the harbour and the town of Marazion, E.N.E. of the Mount.

Mount, but is just such a promontory as would have been selected by foreign traders as well adapted for defence. It

Fig. 61.



Surface and side views of an ancient block of tin dredged up in Falmouth Harbour.

The block is stamped with a small representation of itself as seen in the lower right-hand corner of the drawing.

still affords a good port, daily frequented by vessels, where cargoes of tin are sometimes taken on board, after having

been transported, as in the olden time, at low tide across the isthmus. Colliers of 500 tons' burden can now enter the harbour, which is on the landward or sheltered side of the Mount (as seen in figs. 58, 60), and the depth of water would have sufficed to float the largest vessels which the Phœnicians and other ancient navigators employed when they traded with the Cassiterides, five, if not ten centuries before the Christian era.

According to Carew, the old name of St. Michael's Mount, 'Caraclowse in Cowse,' signifies, in the Cornish language, 'The Hoarę Rock in the wood,' and from this some have inferred that the rock was once surrounded with forest-covered land. At present there are no trees upon the Mount, only a few shrubs, and it is not easy to imagine how such a name could ever have been appropriate since the days of Diodorus, when the Mount was evidently already isolated, and the isthmus such as it is now. Mr. Pengelly has lately entered into a full discussion of this subject,* stating truly, that to make such a name appropriate, we are required to assume that the Mount was surrounded by land covered with trees; a geographical state of things which at once carries us back much more than nineteen centuries, and yet the Cornish language is assumed to have been spoken when the designation of the 'Rock in the Wood' was assigned to the Mount. Whether we endeavour to explain the altered geographical conditions by encroachments of the sea on the land, and the sweeping away of a low tract which once filled the bay, or by a general subsidence of the whole region to a lower level, we should have to assign a date to the old forest anterior to Phœnician times, and thus ascribe a fabulous antiquity to the Cornish tongue. Here, no doubt, as elsewhere, the waves have in the course of the last twenty or thirty centuries converted some tracts of land into sea. Near Penzance, for example, in the same bay, it is recorded that thirty-six acres of pasture land called the Green have been gradually removed and reduced to a bare sandy beach, since the reign of Charles II. It is also known that the grandfather of the present Vicar of Madron (1865) received

* Pengelly, Papers read at Brit. Assoc. Birmingham. 1865

tithe for land which was situated under the cliff at Penzance. Mr. Pengelly also mentions that the coast near Marazion (see fig. 60), which is only a third of a mile distant from the Mount, has yielded slowly at some points within the memory of persons now living, but so gradually that the rate of waste cannot have exceeded ten feet per century; and he calculates that if this cause of change is alone appealed to, it would have taken ten thousand years or more, before our time, to remove so much land as would have stretched from the mainland to the Mount. On the other hand, it is a somewhat forced hypothesis to assume that whereas a retrospect of nineteen centuries displays to us the Mount geographically the same as it now is, yet shortly before that time, when Cornish was spoken, there was a sinking down and submergence of a wooded tract.

There have certainly been depressions here, as in so many other parts of the English coast, but they may have happened very long before the time of history. Thus for example, between Newlyn and St. Michael's Mount, as Boase relates,* there is seen under the sand black vegetable mould full of hazel-nuts, and the branches, leaves, and trunks of forest trees, the elm among others, all of indigenous species. The roots are seen in the soil in their natural position. The wing-cases of insects have also been found among the vegetable matter. The stratum has been traced seaward as far as the ebb permits, and it implies the downward movement of a level tract which preserved its horizontality when subsiding. If we endeavour to form a conjecture as to the probable date of such a submergence, we find ourselves involved in a geological enquiry of vast extent, although the event is so modern as to be comprised within the human period. Thus, to revert again to the Devonshire coast, there is a submerged forest at Torquay, and much peaty matter resting on bluish clay, which may be traced from the neighbourhood of Tor Abbey, at a height of about eighty-four feet above the sea, for three quarters of a mile to the shore. The same bed extends to an unknown distance seaward, many stumps and roots of trees being observed

* Boase, cited by De la Beche in his Report on the Geology of Devon, &c., chap. xiii.

firmly fixed in the clay, and bones of the deer, wild-hog, horse, and the extinct *Bos longifrons* occurring in the peat; with these, the antler of a red-deer was observed by Mr. Pengelly, having several cuts on it made by a sharp instrument, and the whole fashioned into a tool for piercing. From this forest-bed, at a point in the bay where there is a depth of more than thirty feet of water, the fishermen drew up in their trawl, a few years before 1851, the molar tooth of the mammoth, or *Elephas primigenius*, stained with the black colour of the peat, and retaining much of its animal matter, its fresh condition being probably due to the antiseptic quality of the peat. The specimen is now in the Torquay museum, and it is interesting as serving to establish the fact, that the mammoth survived when the surface of this region had already acquired its present configuration, so far as relates to the direction and depth of the valleys in the bottom of one of which the peat alluded to was formed. I mention these facts to show that submarine forests on this coast cannot be safely appealed to in confirmation of changes which may have occurred in the historical period. They may belong to the close of the paleolithic era, although long subsequent to the filling of the caves of Brixham and Kent's Hole, near Torquay, when the elephant, rhinoceros, and cave-bear co-existed with man, before the excavation of some of the valleys which now descend to the sea on this coast.

To return to Cornwall: the oldest historians mention a tradition of the submersion of the Lionnesse, a country said to have stretched from the Land's End to the Scilly Islands. The tract, if it ever existed, must have been thirty miles in length, and perhaps ten in breadth. The land now remaining on either side is from two hundred to three hundred feet high; the intervening sea about three hundred feet deep. Although there is no authentic evidence for this romantic tale, it probably originated in some former inroads of the Atlantic, accompanying, perhaps, a subsidence of land on this coast.

If we then turn to the Bristol Channel, we find that both on the north and south sides of it there are numerous remains of submerged forests; to one of these at Porlock Bay,

on the coast of Somersetshire, Mr. Godwin-Austen* has lately called particular attention, and has shown that it extends far from the land. There is indeed good reason to believe that there was once a woodland tract uniting Somersetshire and Wales, through the middle of which the ancient Severn flowed. The former existence of such land enables us to comprehend how along the southern coast of Glamorganshire fissures and caves in the face of precipitous cliffs at the base of which the sea now beats, may have been inhabited by the hyena and bear, or became the receptacles of the bones of the elephant, rhinoceros, tiger, reindeer and other quadrupeds, most of them now extinct. In one of these caves no less than 1000 antlers of the reindeer were found.

At St. Bride's Bay, in Pembrokeshire, and proceeding farther to the north in Cardiganshire and again in North Wales, (as in Anglesea and Denbighshire,) we have repetitions of the same appearances of ancient forests adjoining the coast. One of these in Anglesea reminds us in a striking manner of the phenomena before mentioned as characterising the forest-bed of Tor Abbey. A bed of peat three feet thick, with the stumps and roots of trees, was observed by the Honourable W. Stanley, exposed at low water in the harbour of Holyhead, and stretching upwards to a slight elevation above the sea, where the excavations made for the railway in 1849 brought to light two perfect heads of the mammoth. The tusks and molars lay two feet below the surface in the peat, which was covered by the stiff blue clay.† It is not improbable that this mammoth survived most of the lost species which were its contemporaries in what has been called the Cavern period. At the same time, we must not forget that the fauna, not only of the bronze age, but of the oldest lake-dwellers of Switzerland to whom the use of metals was unknown, was identical with that of the historical era, no mixture of the bones of the mammoth or of *Bos longifrons*, or even of the reindeer, having been detected, whether among the wild or domestic animals of the lacustrine habitations

* Quart. Geol. Journ. 1866, vol. xxii. p. 1.

† One of these skulls, referred by Prof. Owen to *Elephas Primigenius*, has been presented to the British Museum by the Hon. W. Stanley, M.P., on whose property they were found.

of Switzerland or in the kitchen-middens of Denmark. If, therefore, all the littoral, sunk forests of the south and west of England are referable to about the same geological period, the occasional presence in them of the mammoth will entitle them to be regarded as very ancient, or of a date intervening between the era of the lake-dwellings and that of the oldest epoch to which man has yet been traced back.

West coast of England.—Having now brought together an ample body of proofs of the destructive operations of the waves, tides, and currents, on our eastern and southern shores, it will be unnecessary to enter into details of changes on the western coast, for they present merely a repetition of the same phenomena, and in general on an inferior scale. On the borders of the estuary of the Severn the flats of Somersetshire and Gloucestershire have received enormous accessions, while, on the other hand, the coast of Cheshire, between the rivers Mersey and Dee, has lost, since the year 1764, many hundred yards, and some affirm more than half a mile, by the advance of the sea upon the abrupt cliffs of red clay and marls. Within the period above mentioned several lighthouses have been successively abandoned.* There are traditions in Pembrokeshire † and Cardiganshire ‡ of far greater losses of territory than that which the Lionnesse tale of Cornwall pretends to commemorate. They are all important, as demonstrating that the earliest inhabitants were familiar with the phenomenon of incursions of the sea.

Loss of land on the coast of France.—The French coast, particularly that of Brittany, where the tides rise to an extraordinary height, is the constant prey of the waves. In the ninth century many villages and woods are reported to have been carried away, the coast undergoing great change, whereby the hill of St. Michel was detached from the mainland. The parish of Bourgneuf, and several others in that neighbourhood, were overflowed in the year 1500. In 1735, during a great storm, the ruins of Palnel were seen uncovered in the sea.§

* Stevenson, Jameson's Ed. New Phil. Journ. No. 8. p. 386.

† Camden, who cites Giraldus; also Ray, 'On the Deluge,' Phys. Theol., p. 228.

‡ Meyrick's Cardigan.

§ Von Hoff, Geschichte, &c. vol. i p. 49.

CHAPTER XXI.

ACTION OF TIDES AND CURRENTS—*continued.*

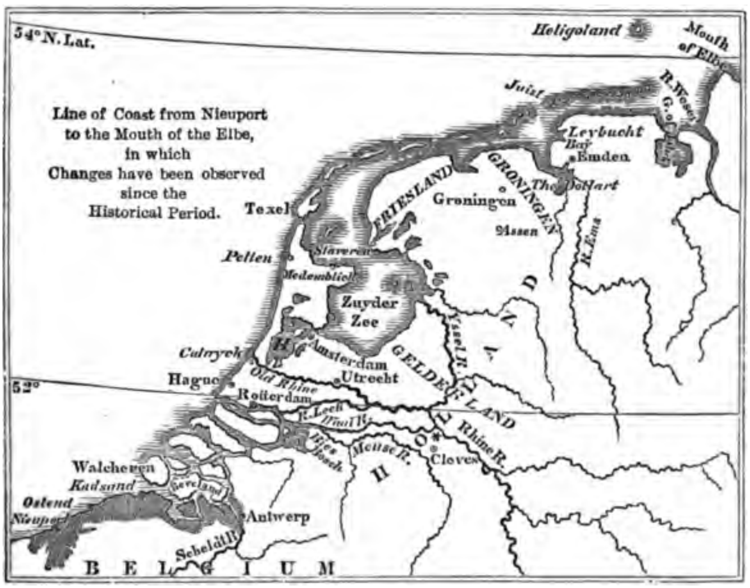
INROADS OF THE SEA AT THE MOUTHS OF THE RHINE IN HOLLAND—CHANGES IN THE ARMS OF THE RHINE—PROOFS OF SUBSIDENCE OF LAND—ESTUARY OF THE BIES BOSCH, FORMED IN 1421—ZUYDER ZEE, IN THE THIRTEENTH CENTURY—ISLANDS DESTROYED—DELTA OF THE EMS CONVERTED INTO A BAY—ESTUARY OF THE DOLLART FORMED—ENCROACHMENT OF THE SEA ON THE COAST OF SLESWICK—ON THE SHORES OF NORTH AMERICA—BALTIC CURRENTS—CIMBRIAN DELUGE—TIDAL WAVE, CALLED THE BORE.

Inroads of the sea at the mouths of the Rhine.—THE line of British coast considered in the preceding chapter offered no example of the conflict of two great antagonist forces; the influx, on the one hand, of a river draining a large continent, and, on the other, the action of the waves, tides, and currents of the ocean. But when we pass over by the Straits of Dover to the Continent, and proceed north-eastwards, we find an admirable illustration of such a contest, where the ocean and the Rhine are opposed to each other, each disputing the ground now occupied by Holland; the one striving to shape out an estuary, the other to form a delta. There was evidently a period when the river obtained the ascendency, when the shape and perhaps the relative level of the coast and set of the tides were very different; but for the last two thousand years, during which man has witnessed and actively participated in the struggle, the result has been in favour of the ocean; the area of the whole territory having become more and more circumscribed; natural and artificial barriers have given way, one after another; and many hundred thousand human beings have perished in the waves.

Changes in the arms of the Rhine.—The Rhine, after flowing from the Grison Alps, copiously charged with sediment, first purifies itself in the Lake of Constance, where a large delta

is formed; then swelled by the Aar and numerous other tributaries, it flows for more than six hundred miles towards the north; when, entering a low tract, it divides into two arms, about ten miles north-east of Cleves,—a point which may be considered the head of its delta. (See*, map, fig. 62.) In speaking of the delta, I do not mean to assume that all that part of Holland which is comprised within the several arms of the Rhine can be called a delta in the

Fig. 62.



The dark tint between Antwerp and Nieuport represents part of the Netherlands which was land in the time of the Romans, then overflowed by the sea before and during the 5th century, and afterwards reconverted into land.

The letter H west of Amsterdam indicates the Lake of Haarlem drained in 1853, and turned into arable land 13 feet below the sea-level.

strictest sense of the term; because some portion of the country thus circumscribed, as, for example, a part of Gelderland and Utrecht, consists of strata which may have been deposited in the sea before the Rhine existed. These older tracts may either have been raised like the Ullah Bund in

Cutch, during the period when the sediment of the Rhine was converting a part of the sea into land, or they may have constituted islands previously.

When the river divides north of Cleves, the left arm takes the name of the Waal; and the right, retaining that of the Rhine, is connected, a little farther to the north, by an artificial canal with the river Yssel. The Rhine then flowing westward divides again south-east of Utrecht, and from this point it takes the name of the Leck, a name which was given to distinguish it from the northern arm called the Old Rhine, which was sanded up until after the year 1825, when a channel was cut for it, by which it now enters the sea at Catwyck. It is common, in all great deltas, that the principal channels of discharge should shift from time to time, but in Holland so many magnificent canals have been constructed, and have so diverted, from time to time, the course of the waters, that the geographical changes in this delta are endless, and their history, since the Roman era, forms a complicated topic of antiquarian research. The present head of the delta is about forty geographical miles from the nearest part of the gulf called the Zuyder Zee, and more than twice that distance from the general coast-line. The present head of the delta of the Nile is about 80 or 90 geographical miles from the sea; that of the Ganges, as before stated, 220; and that of the Mississippi about 180, reckoning from the point where the Atchafalaya branches off to the extremity of the new tongue of land in the Gulf of Mexico. But the comparative distance between the heads of deltas and the sea affords no positive data for estimating the relative magnitude of the alluvial tracts formed by their respective rivers, for the ramifications depend on many varying and temporary circumstances, and the area over which they extend does not hold any constant proportion to the volume of water in the river.

The Rhine, for instance, has at present three mouths. About two-thirds of its waters flow to the sea by the Waal, and the remainder is carried partly to the Zuyder Zee by the Yssel, and partly to the ocean by the Leck. As the whole coast to the south as far as Ostend, and on the north to the entrance of the Baltic, has, with few exceptions, from time

immemorial, yielded to the force of the waves, it is evident that the common delta of the Rhine, Meuse, and Scheldt, (for these three rivers may all be considered as discharging their waters into the same part of the sea,) would, if its advance had not been checked, have become extremely prominent; and even if it had remained stationary, would long ere this have projected far beyond the rounded outline of the coast, like that strip of land already described at the mouth of the Mississippi. But we find, on the contrary, that the islands which skirt the coast have not only lessened in size, but in number also, while great bays have been formed in the interior by incursions of the sea.

In order to explain the incessant advance of the ocean on the shores and inland country of Holland, M. E. de Beaumont has suggested that there has in all probability been a general depression or sinking of the land below its former level over a wide area. Such a change of level would enable the sea to break through the ancient line of sand-banks and islands which protected the coast—would lead to the enlargement of bays, the formation of new estuaries, and ultimately to the entire submergence of land. These views appear to be supported by the fact that several peat-mosses of freshwater origin now occur under the level of the sea, especially on the site of the Zuyder Zee and Lake Flevo, presently to be mentioned. Several excavations also made for wells at Utrecht, Amsterdam, and Rotterdam have proved, that below the level of the ocean, the soil near the coast consists of alternations of sand with marine shells, and beds of peat and clay, which have been traced to the depth of fifty feet and upwards.*

I have said that the coast to the south as far as Ostend has given way. This statement may at first seem opposed to the fact, that the tract between Antwerp and Nieuport, shaded black in the map (fig. 62, p. 553), although now dry land, and supporting a large population, has, within the historical period, been covered with the sea. This region, however, consisted, in the time of the Romans, of woods marshes, and peat-mosses, protected from the ocean by a

* M. E. de Beaumont, Géologie Pratique, vol. i. p. 316, and ibid. p. 260.

chain of sandy dunes, which were afterwards broken through during storms, especially in the fifth century. The waters of the sea during these irruptions threw down upon the barren peat a horizontal bed of fertile clay, which is in some places three yards thick, full of recent shells and works of art. The inhabitants, by the aid of embankments and the sand dunes of the coast, have succeeded, although not without frequent disasters, in defending the soil thus raised by the marine deposit.*

Inroads of the sea in Holland.—If we pass to the northward of the territory just alluded to, and cross the Scheldt, we find that between the fourteenth and eighteenth centuries parts of the islands Walcheren and Beveland were swept away, and several populous districts of Kadsand—losses which far more than counterbalance the gain of land caused by the sanding-up of some pre-existing creeks. In 1658 the island Orisant was annihilated. One of the most memorable inroads of the sea occurred in 1421, when the tide, pouring into the mouth of the united Meuse and Waal, burst through a dam in the district between Dort and Gertrudenberg, and overflowed seventy-two villages, forming a large sheet of water called the Bies Bosch. (See map, fig. 62.) Thirty-five of the villages were irretrievably lost, and no vestige, even of their ruins, was afterwards seen. The rest were redeemed, and the site of the others, though still very generally represented on maps as an estuary, has in fact been gradually filled up by alluvial deposits, and had become in 1835, as I was informed by Professor Moll, an immense plain, yielding abundant crops of hay, though still uninhabited. To the north of the Meuse is a long line of shore covered with sand dunes, where great encroachments have taken place from time to time, in consequence chiefly of the prevalence of south-easterly winds, which blow down the sands towards the sea. The church of Scheveningen, not far from the Hague, was once in the middle of the village, and now stands on the shore, half the place having been overwhelmed by the waves in 1570. Catwyck, once far from the

* Belpaire. Mém. de l'Acad. Roy. de Bruxelles, tom. x. 1837. Dumont, Bulletin of the same Soc. tom. v. p. 643.

sea, is now upon the shore; two of its streets having been overflowed, and land torn away to the extent of 200 yards in 1719. It is only by aid of embankments that Petten, and several other places farther north, have been defended against the sea.

In 1853, the Dutch Government laid dry, by means of steam power, a great sheet of water westward of Amsterdam, formerly called the lake of Haarlem, and so represented in our map H (fig. 62), extending over 45,000 acres. This gained land lies thirteen feet beneath the mean level of the ocean; and in 1859, when I visited it, supported an agricultural population of 5,000 souls.*

Formation of the Zuyder Zee and Straits of Staveren.—Still more important are the changes which have taken place on the coast opposite the right arm of the Rhine, or the Yssel, where the ocean has burst through a large isthmus, and entered the inland lake Flevo, which, in ancient times, was, according to Pomponius Mela, formed by the overflowing of the Rhine over certain lowlands. It appears that, in the time of Tacitus, there were several lakes on the present site of the Zuyder Zee, between Friesland and Holland. The successive inroads by which these, and a great part of the adjoining territory, were transformed into a great gulf, began about the commencement, and were completed towards the close, of the thirteenth century. Alting gives the following relation of the occurrence, drawn from manuscript documents of contemporary inhabitants of the neighbouring provinces. In the year 1205, the island now called Wieringen, to the south of the Texel, was still a part of the mainland, but during several high floods, of which the dates are given, ending in December 1251, it was separated from the continent. By subsequent incursions, the sea consumed great parts of the rich and populous isthmus, a low tract which stretched on the north of Lake Flevo, between Staveren in Friesland and Medemblick in Holland (see map, fig. 62), till at length a breach was completed about the year 1282, and afterwards widened. Great destruction of land took

* For a fuller description of this drained tract, See Lyell's 'Antiquity of Man, p. 147.

place when the sea first broke in, and many towns were swept away; but there was afterwards a reaction to a certain extent, large tracts, at first submerged, having been gradually redeemed. The new straits south of Staveren are more than half the width of those of Dover, but are very shallow, the greatest depth not exceeding two or three fathoms. The new bay is of a somewhat circular form, and between *thirty* and *forty* miles in diameter. How much of this space may formerly have been occupied by Lake Flevo is unknown.

Destruction of islands.—A series of islands stretching from

Fig. 63.

View of part of the island of Heligoland with Sandy Island.

a. Sandy Island in the distance, said to have been formerly united with the main island.

b b. Strata of a light green colour separating the beds of red marl and sandstone

the Texel to the mouths of the Weser and Elbe are probably the last relics of a tract once continuous. They have greatly diminished in size, and have lost about a third of their number, since the time of Pliny; for that naturalist counted twenty-three islands between the Texel and the Eider, in Schleswig-Holstein, whereas there are now only sixteen, in-

cluding Heligoland and Neuwerk.* The island of Heligoland, at the mouth of the Elbe, consists of a rock of red marl and sandstone of the Trias formation (or Keuper and Bunter of the Germans), and is bounded by perpendicular red cliffs, above 200 feet high. (See fig. 63.) Although, according to some accounts, it has been greatly reduced in size since the year 800, M. Wiebel assures us, that the ancient map by Meyer cannot be depended upon, and that the island, according to the description still extant by Adam of Bremen, was not much larger than now, in the time of Charlemagne. On comparing the map made in the year 1793 by the Danish engineer Wessel, the average encroachment of the sea on the cliffs, between that period and 1848 (or about half a century), amounted to about three feet a year for the whole circumference of the island.† According to some authorities, Sandy Island (see *a*, fig. 63), now separated from Heligoland by a navigable channel, formed, within the memory of man, a portion of the larger island. On the other hand, some few islands off the Dutch and Danish coasts have extended their bounds in one direction, or become connected with others, by the sanding-up of channels; but even these, like Juist, have generally given way as much on the north towards the sea as they have gained on the south, or land side.

The Dollart formed.—While the delta of the Rhine has suffered so materially from the movements of the ocean, it can hardly be supposed that minor rivers on the same coast should have been permitted to extend their deltas. It appears that in the time of the Romans there was an alluvial plain of great fertility, where the Ems entered the sea by three arms. This low country stretched between Groningen and Friesland, and sent out a peninsula to the north-east towards Emden. (See map, fig. 62.) A flood in 1277 first destroyed part of the peninsula. Other inundations followed at different periods throughout the fifteenth century. In 1507, a part only of Torum, a considerable town, remained standing; and in spite of the erection of dams, the remainder

* Von Hoff, vol. i. p. 364.
† Quart. Journ. Geol. Soc. vol. iv. p. 32; Memoirs.

of that place, together with market-towns, villages, and monasteries, to the number of fifty, were finally overwhelmed. The new gulf, which was called the Dollart, although small in comparison to the Zuyder Zee, occupied no less than six square miles at first; but part of this space was, in the course of the two following centuries, again redeemed from the sea. The small bay of Leybucht, farther north, was formed in a similar manner in the thirteenth century; and the bay of Harlbucht in the middle of the sixteenth. Both of these have since been partially reconverted into dry land. Another new estuary, called the Gulf of Jahde, near the mouth of the Weser, scarcely inferior in size to the Dollart, has been gradually hollowed out since the year 1016, between which era and 1651 a space of about four square miles has been added to the sea. The rivulet which now enters this inlet is very small; but Aren conjectures, that an arm of the Weser had once an outlet in that direction.

Coast of Schleswig.—Farther north we find so many records of waste on the western coast of Schleswig, as to lead us to anticipate that, at no distant period in the history of the physical geography of Europe, Jutland may become an island, and the ocean may obtain a more direct entrance into the Baltic. Indeed, the temporary insulation of the northern extremity of Jutland has been effected no less than four times within the records of history, the ocean having as often made a breach through the bar of sand, which usually excludes it from the Lym Fiord. This long frith is 120 miles in length including its windings, and communicates at its eastern end with the Baltic. The last irruption of salt water happened in 1824, and the fiord was still open in 1837, when some vessels of thirty tons' burden passed through.

The Marsh islands between the rivers Elbe and Eider are mere banks, like the lands formed of the 'warp' in the Humber, protected by dikes. Some of them, after having been inhabited with security for more than ten centuries, have been suddenly overwhelmed. In this manner, in 1216, no less than 10,000 of the inhabitants of Eiderstede and Ditmarsch perished; and on the 11th of October, 1634, the

islands and the whole coast, as far as Jutland, suffered by a dreadful deluge.

Destruction of Nordstrand by the sea.—Nordstrand, up to the year 1240, was, with the islands Sylt and Föhr (see map, fig. 64), so nearly connected with the mainland as to appear a

Fig. 64.

Line of coast from the north of Holland to the Baltic, showing the position of islands which have suffered waste in the historical period.

peninsula, and was called North Friesland, a highly cultivated and populous district. It measured from nine to eleven geographical miles from north to south, and six to eight from east to west. In the above-mentioned year it was torn asunder from the continent, and in part overwhelmed. The

Isle of Nordstrand, thus formed, was, towards the end of the sixteenth century, only sixteen geographical miles in circumference, and was still celebrated for its cultivation and numerous population. After many losses, it still contained 9,000 inhabitants. At last, in the year 1634, on the evening of the 11th of October, a flood passed over the whole island, whereby 1,300 houses, with many churches, were lost; above 6,000 men perished, and 50,000 head of cattle. Three small islets, one of them still called Nordstrand, alone remained, which are now continually wasting.

The redundancy of river water in the Baltic, especially during the melting of ice and snow in spring, causes in general an outward current through the channel called the Cattegat. But after an unusual continuance of north-westerly gales, especially during the height of the spring-tides, the Atlantic rises, and pouring a flood of water into the Baltic, commits dreadful devastations on the isles of the Danish Archipelago. This current even acts, though with diminished force, as far eastward as the vicinity of Dantzic.* Accounts written during the last ten centuries attest the wearing down of promontories on the Danish coast, the deepening of gulfs, the severing of peninsulas from the mainland, and the waste of islands, while in several cases marsh land, defended for centuries by dikes, has at last been overflowed, and thousands of the inhabitants overwhelmed in the waves. Thus the island Barsoe, on the coast of Schleswig, (see fig. 64) has lost, year after year, an acre at a time, and the island Alsen suffers in like manner.

Cimbrian deluge.—As we have already seen that during the flood above mentioned, 6,000 men and 50,000 head of cattle perished on Nordstrand on the western coast of Jutland, we are well prepared to find that this peninsula, the Cimbrica Chersonesus of the ancients, has from a remote period been the theatre of like catastrophes. Accordingly, Strabo records a story, although he treats it as an incredible fiction, that, during a high tide, the ocean rose upon this coast so rapidly, that men on horseback were scarcely able to escape.†

* See examples in Von Hoff, vol. i. p. 73 who cites Pisansky.

† Book vii. Cimbri.

Florus, alluding to the same tradition, says, 'The Cimbrians, Teutons, and Tigurini, flying from the extreme limits of Gaul, when the ocean had overflowed their territory, were looking out in all parts of the world for new settlements.'* This event, commonly called the 'Cimbrian Deluge,' is supposed to have happened about three centuries before the Christian era; but it is not improbable that the principal catastrophe was preceded and followed by many devastations like those experienced in modern times on the islands and shores of Jutland, and such calamities may well be conceived to have forced on the migration of some maritime tribes.

Inroads of the sea on the eastern shores of North America.—After so many authentic details respecting the destruction of the coast in parts of Europe best known, it will be unnecessary to multiply examples of analogous changes in more distant regions of the world. It must not, however, be imagined that our own sea coasts are wearing away at an exceptionally rapid rate. Thus, for example, if we pass over to the eastern coast of North America, where the tides rise in the Bay of Fundy, to a great elevation, we find many facts attesting the incessant demolition of land. Cliffs, often several hundred feet high, composed of sandstone, red marl, and other rocks, which border that bay and its numerous estuaries, are perpetually undermined. The ruins of these cliffs are gradually carried, in the form of mud, sand, and large boulders, into the Atlantic by powerful currents, aided at certain seasons by drift ice, which forms along the coast, and freezes round large stones.

At Cape May, on the north side of Delaware Bay, in the United States, the encroachment of the sea was shown by observations made consecutively for sixteen years, from 1804 to 1820, to average about nine feet a year;† and at Sullivan's Island, which lies on the north side of the entrance of the harbour of Charlestown, in South Carolina, the sea carried away a quarter of a mile of land in three years ending in 1786.‡

* 'Cimbri, Teutoni, atque Tigurini, ab extremis Galliæ profugi, cum terras eorum inundasset Oceanus, novas sedes toto orbe quærebant.'—Lib. iii. cap. 3.

† New Monthly Mag. vol. vi. p. 69.

‡ Von Hoff. vol. i. p. 96.

Tidal wave called 'the Bore.'—Before concluding my remarks on the action of the tides, I must not omit to mention the wave called 'the Bore,' which is sometimes produced in a river where a large body of water is made to rise suddenly, in consequence of the narrowing of the channel. The wave terminates abruptly on the inland side; because the quantity of water contained in it is so great, and its motion so rapid, that time is not allowed for the surface of the river to be immediately raised by means of transmitted pressure. A tide wave thus rendered abrupt has a close analogy, observes Dr. Whewell, to the waves which curl over and break on a shelving shore.*

The Bore which enters the Severn, where the phenomenon is of almost daily occurrence, is sometimes nine feet high, and at spring-tides rushes up the estuary with extraordinary rapidity. The finest example which I have seen of this wave was in Nova Scotia,† where the tide is said to rise in some places seventy feet perpendicular, and to be the highest in the world. In the large estuary of the Shubenacadie, which is connected with another estuary called the Basin of Mines, itself an embranchment of the Bay of Fundy, a vast body of water comes rushing up, with a roaring noise, into a long narrow channel, and while it is ascending, has all the appearance of pouring down a slope as steep as that of the celebrated rapids of the St. Lawrence. In picturesque effect, however, it bears no comparison, for instead of the transparent green water and snow-white foam of the St. Lawrence, the whole current of the Shubenacadie is turbid and densely charged with red mud. The same phenomenon is frequently witnessed in the principal branches of the Ganges and in the Megna as before mentioned (p. 475). 'In the Hoogly,' says Rennel, 'the Bore commences at Hoogly Point, the place where the river first contracts itself, and is perceptible above Hoogly Town; and so quick is its motion, that it hardly employs four hours in travelling from one to the other, though the distance is nearly seventy miles. At Calcutta it sometimes occasions an instantaneous rise of five

* Phil. Trans. 1833, p. 204.

† See Lyell's Travels in North America, in 1842, vol. ii. p. 166. London. 1845.

feet; and both here, and in every other part of its track, the boats, on its approach, immediately quit the shore, and make for safety to the middle of the river. In the channels, between the islands in the mouth of the Megna, the height of the Bore is said to exceed twelve feet; and is so terrific in its appearance, and dangerous in its consequences, that no boat will venture to pass at spring-tide.' * These waves may sometimes cause inundations, undermine cliffs, and still more frequently sweep away trees and land animals from low shores, so that they may be carried down, and ultimately imbedded in fluviatile or submarine deposits.

* Rennel, Phil. Trans. 1781.

CHAPTER XXII.

REPRODUCTIVE EFFECTS OF TIDES AND CURRENTS.

DEPOSITING POWER OF TIDAL CURRENTS—SILTING UP OF ESTUARIES DOES NOT COMPENSATE THE LOSS OF LAND ON THE BORDERS OF THE OCEAN—ORIGIN OF SHOALS AND VALLEYS IN THE BED OF THE GERMAN OCEAN—COMPOSITION AND EXTENT OF ITS SAND-BANKS—STRATA DEPOSITED BY CURRENTS IN THE ENGLISH CHANNEL—AT THE MOUTHS OF THE AMAZONS, ORINOCO, AND MISSISSIPPI—WIDE AREA OVER WHICH STRATA MAY BE FORMED BY THIS CAUSE.

Depositing power of tidal currents.—FROM the facts enumerated in the last chapter, it appears that on the borders of the ocean, currents and tides co-operating with the waves of the sea are most powerful instruments in the destruction and transportation of rocks; and as numerous tributaries discharge their alluvial burden into the channel of one great river, so we find that many rivers deliver their earthy contents to one marine current, to be borne by it to a distance, and deposited in some deep receptacle of the ocean. The current, besides receiving this tribute of sedimentary matter from streams draining the land, acts also itself on the coast, as does a river on the cliffs which bound a valley. Yet the waste of the cliffs by marine currents constitutes on the whole a very insignificant portion of the denudation annually effected by aqueous causes, as I shall point out in the sequel of this chapter (p. 572).

In inland seas, where the tides are insensible, or on those parts of the borders of the ocean where they are feeble, it is scarcely possible to prevent a harbour at a river's mouth from silting up; for a bar of sand or mud is formed at points where the velocity of the turbid river is checked by the sea, or where the river and a marine current neutralise each

other's force. For the current, as we have seen, may, like the river, hold in suspension a large quantity of sediment, or, co-operating with the waves, may cause the progressive motion of a shingle beach in one direction. I have already alluded to the erection of piers and groins at certain places on our southern coast, to arrest the course of the shingle and sand (see p. 536). The immediate effect of these temporary obstacles is to cause a great accumulation of pebbles on one side of the barrier, after which the beach still moves on round the end of the pier at a greater distance from the land. This interference, however, with the natural course or movement of the materials of the beach is often attended with a serious evil, for during storms the waves throw suddenly into the harbour the vast heap of pebbles which have collected for years behind the groin or pier, as happened during a great gale (Jan. 1839) at Dover.

The formation and keeping open of large estuaries are due to the *combined influence* of tidal currents and rivers; for when the tide rises, a large body of water suddenly enters the mouth of the river, where, becoming confined within narrow bounds, while its momentum is not destroyed, it is urged on, and, having to pass through a contracted channel, rises and runs with increased velocity, just as a stream when it reaches the arch of a bridge scarcely large enough to give passage to its waters, rushes with a steep fall through the arch. During the ascent of the tide, a body of fresh water, flowing down from the inland country, is arrested in its course for several hours; and thus a large lake of fresh and brackish water is accumulated, which when the sea ebbs, is let loose, as on the removal of an artificial sluice or dam. By the force of this retiring water, the alluvial sediment both of the river and of the sea is swept away, and transported to such a distance from the mouth of the estuary, that a small part only can return with the next tide.

It sometimes happens, that during a violent storm a large bar of sand is suddenly made to shift its position, so as to prevent the free influx of the tides, or efflux of river water. Thus about the year 1500 the sands at Bayonne were suddenly thrown across the mouth of the Adour. The river,

flowing back upon itself, soon forced a passage to the northward along the sandy plain of Capbreton, till at last it reached the sea at Boucau, at the distance of *seven leagues* from the point where it had formerly entered. It was not till the year 1579 that the celebrated architect Louis de Foix undertook, at the desire of Henry III., to re-open the ancient channel, which he at last effected with great difficulty.*

In the estuary of the Thames at London, and in the Gironde, the tide rises only for five hours and ebbs seven, and in all estuaries the water requires a longer time to run down than up; so that the preponderating force is always in the direction which tends to keep open a deep and broad passage. But for reasons already explained, there is naturally a tendency in all estuaries to silt up partially, since eddies, and backwaters, and points where opposing streams meet, are very numerous, and constantly change their position.

Many writers have declared that the gain on our eastern coast, since the earliest periods of history, has more than counterbalanced the loss; but they have been at no pains to calculate the amount of loss, and have often forgotten that, while the new acquisitions are manifest, there are rarely any natural monuments to attest the former existence of the land that has been carried away. They have also taken into their account those tracts artificially recovered, which are often of great agricultural importance, and may remain secure, perhaps, for thousands of years, but which are only a few feet above the mean level of the sea, and are therefore exposed to be overflowed again by a small proportion of the force required to move cliffs of considerable height on our shores. If it were true that the area of land annually abandoned by the sea in estuaries were equal to that invaded by it, there would still be no compensation *in kind.*

The tidal current which flows out from the north-west, and which, deflected and confined in the German Ocean, bears against the eastern coast of England, transports, as we have seen, materials of various kinds. Aided by the waves, it undermines and sweeps away the granite, gneiss, trap rocks, and sandstone of Shetland, and removes the

* Nouvelle Chronique de la Ville de Bayonne, pp. 113, 139. 1827.

gravel and loam of the cliffs of Holderness, Norfolk, and Suffolk, which are between twenty and three hundred feet in height, and which waste at various rates of from one foot to six yards annually. It also bears away, in co-operation with the Thames and the tides, the strata of London clay on the coasts of Essex and Sheppey. The sea at the same time consumes the chalk with its flints for many miles continuously on the shores of Kent and Sussex—commits annual ravages on the freshwater beds, capped by a thick covering of chalk-flint gravel, in Hampshire, and continually saps the foundation of the Portland limestone. It receives, besides, during the rainy months, large supplies of pebbles, sand, and mud, which numerous streams from the Grampians, Cheviots, and other chains, send down to the sea. To what regions, then, is all this matter consigned? It is not retained in mechanical suspension by the waters of the ocean, nor does it mix with them in a state of chemical solution,—it is deposited *somewhere*, yet certainly not in the immediate neighbourhood of our shores; for, in that case, there would soon be a cessation of the encroachment of the sea, and large tracts of low land, like Romney Marsh, would almost everywhere encircle our island.

As there is now a depth of water, exceeding thirty feet in some spots where towns like Dunwich flourished but a few centuries ago, it is clear that the current not only carries far away the materials of the wasted cliffs, but is capable also of keeping clear the bed of the sea to a certain moderate depth.

Origin of shoals and valleys in the bottom of the German Ocean.—To what extent in a downward direction this power of submarine erosion extends, is a question of the highest geological interest, and one respecting which we have at present no very accurate information. The sea between Great Britain and the Continent of Europe has rarely a depth of more than 50 fathoms, and the only part which exceeds 100 fathoms is a narrow channel skirting the western coast of Norway and Sweden, which varies from 200 to 300 fathoms, and attains at one point, near the entrance of the Baltic, the extraordinary depth of 430 fathoms, or 2,580 feet. Some hydrographers are of opinion that even this channel

has been scooped out by a tidal current, but to me it appears more probable that it indicates the original depth of this part of the ocean where fresh sediment has not been thrown down.

Nevertheless, there are some submarine valleys, or long narrow ravines traversing the shallow parts of the German Ocean, which seem to have been due to a tidal current, capable either of scouring out a channel, or of keeping one clear by not allowing it to become the receptacle of matter drifted towards it from the nearest coast. Of this nature is the depression called the Outer Silver Pits, about 60 miles due east of Flamborough Head, the deepest part of which is about 40 fathoms, or 240 feet. If the Mississippi, with a surface velocity of three miles an hour, can push along sand and gravel at the bottom, and keep open a channel from 150 to 200 feet in depth, a marine current, sometimes flowing at a still greater rate, may well be supposed to excavate or keep clear the Silver Pits. Mr. Murray in the memoir explanatory of his map of the North Sea, in which he has embodied the results of Captain Hewitt's survey, assumes that this ravine, as well as the Inner Silver Pits, near the mouth of the Humber, have been scooped out by the tidal current, whereas the great shoals north and south of the Silver Pits are areas in which drift matter and comminuted shells are constantly heaped up in comparatively tranquil water. The great shoal to the north, called the Dogger Bank, about 60 miles east of the coast of Northumberland, is no less than 200 miles in its longest diameter; it has been compared in size to the whole principality of Wales. In this area there is one tract 75 miles long and 20 broad, nowhere exceeding 15 fathoms in depth, while the shallowest parts were found by Captain Hewitt to be only 42 feet under water, and in one place the wreck of a ship had caused it to be still shallower. South of the Silver Pits there is another vast area of shoals, which we may safely regard as the receptacle both of sediment brought down by rivers and of matter derived from the waste of the British coast. Entire as well as broken shells are dredged up on the Dogger and other banks over which fishermen annually trawl their nets. Currents running sometimes from the north, and sometimes from the south, remove parts of the

banks during heavy gales, causing the sands to shift their position, in which case the strata, when re-deposited, must greatly resemble the so-called crag of Norfolk and Suffolk. Nor can there fail, in the course of ages, to be spots where some of the unconsolidated older tertiary formations, such, for example, as the Bagshot sand and London clay, will be denuded with as much facility as the modern sand-banks; such denudation would inevitably take place during oscillations in the level of the bottom of the sea, like those which we know to have occurred during and since the Glacial Epoch. Whenever the sea scooped out such channels in the ancient strata, fossil shells of extinct species would be mingled with recent ones, and both the one and the other would often be more or less rolled. As the bones also of the elephant and other extinct mammalia are occasionally dredged up with oysters attached to them, from the bed of the sea between Suffolk and the Netherlands, such fossil bones would be occasionally included in the new formations. The chief difference in character between the Pliocene and modern strata will consist in the intermixture in the latter of works of art together with the bones of man; monuments of hundreds, nay thousands, of wrecked vessels, which in the last twenty centuries have sunk on these banks, and so impeded for a time the free passage over them of shelly sand, as to produce shoals reaching within thirty feet of the surface.

So great is the quantity of mud held in suspension by the tidal current on our shores, that it is found useful artificially to introduce the water into certain lands reclaimed from the sea and which are below the level of high tide; and by repeating this operation, which is called 'warping,' for two or three years, considerable tracts have been raised, in the estuary of the Humber, to the height of about six feet above their former level. If a current, charged with such materials, meets with deep depressions in the bed of the ocean, it must often fill them up; just as a river, when it meets with a lake in its course, fills it gradually with sediment.

Comparative efficacy of rivers and currents as transporting and denuding agents.—I have said (p. 566) that the action of

the waves and currents on sea-cliffs, or their power to remove matter from above to below the sea-level, is insignificant in comparison with the power of rivers to perform the same task. As an illustration we may take the coast of Holderness, described in Chap. XX. (p. 514). It is composed, as we have seen, of very destructible materials, is thirty-six miles long, and its average height may be taken at forty feet. As it has wasted away at the rate of two and a quarter yards annually, for a long period, it will be found on calculation that the quantity of matter thrown down into the sea every year, and removed by the current, amounts to 51,321,600 cubic feet. It has been shown that the united Ganges and Brahmapootra carry down to the Bay of Bengal 40,000,000,000 of cubic feet of solid matter every year, so that their transporting power is no less than 780 times greater than that of the sea on the coast above mentioned; and in order to produce a result equal to that of the two Indian rivers, we must have a line of wasting coast, like that of Holderness, nearly 28,000 miles in length, or longer than the entire circumference of the globe by above 3,000 miles. The reason of so great a difference in the results may be understood when we reflect that the operations of the ocean are limited to a single line of cliff surrounding a large area, whereas great rivers with their tributaries, and the mountain torrents which flow into them, act simultaneously on a length of bank almost indefinite.

Nevertheless we are by no means entitled to infer, that the denuding force of the great ocean is a geological cause of small efficacy, or inferior to that of rivers. Its chief influence is exerted at moderate depths below the surface, on all those areas which are slowly rising, or are attempting, as it were, to rise above the sea. From data hitherto obtained respecting subterranean movements, we can scarcely speculate on an average rate of upheaval of more than two or three feet in a century. An elevation to this amount is taking place in Scandinavia, and probably in many submarine areas as vast as those which we know to be sinking from the proofs derived from circular lagoon islands or coral atolls.*

* See the last chapter in Vol. II.

Suppose strata as destructible as the greater part of the Tertiary, Cretaceous, and Wealden deposits of the British Isles, or the coal-measures or mud-stones of the Silurian periods, to be thus slowly upheaved, how readily might they all be swept away by waves and currents in an open sea! How entirely might each stratum disappear as it was brought up successively and exposed to the breakers! Shoals of wide extent might be produced, but it is difficult to conceive how any continent could ever be formed under such circumstances. Were it not indeed for the hardness and toughness of some limestones and of many crystalline and volcanic rocks which are often capable of resisting the action of the waves, few lands might ever emerge from the midst of an open sea.

Arrangement of materials in current deposits and their wide diffusion.—It has been ascertained by soundings in all parts of the world, that where new deposits are taking place in the sea, coarse sand and small pebbles commonly occur near the shore, while farther from land, and in deeper water, finer sand and broken shells are spread out over the bottom. Still farther out, the finest mud and ooze are alone met with. Mr. Austen observes that this rule holds good in every part of the English Channel examined by him. He also informs us, that where the tidal current runs rapidly in what is called 'races,' where surface undulations are perceived in the calmest weather, over deep banks, the discoloration of the water does not arise from the power of such a current to disturb the bottom at a depth of 40 to 80 fathoms, as some have supposed. In these cases, a column of water sometimes 500 feet in height, is moving onwards with the tide clear and transparent above, while the lower portion holds fine sediment in suspension (a fact ascertained by soundings), when suddenly it impinges upon a bank, and its height is reduced to 300 feet. It is thus made to boil up and flow off at the surface, a process which forces up the lower strata of water charged with fine particles of mud, which in their passage from the coast had gradually sunk to a depth of 300 feet or more.*

One characteristic effect of the action of currents is, the

* Robt. A. C Austen, Quart. Journ. Geol. Soc. vol. vi. p. 76.

immense extent over which they may be the means of diffusing homogeneous mixtures. Even off coasts where there are no large rivers, they may still have the power of spreading far and wide over the bottom of the ocean, not only sand and pebbles, but the finest mud. Thus for *several thousand miles* along the western coast of South America, comprising the larger parts of Peru and Chili, there is a perpetual rolling of shingle along the shore, part of which, as Mr. Darwin has shown, is incessantly reduced to the finest mud by the waves, and swept into the depths of the Pacific by the tides and currents. The same author, however, has remarked that, notwithstanding the great force of the waves on that shore, all rocks 60 feet under water are covered by sea-weed, showing that the bed of the sea is not denuded at that depth, the effect of the winds being comparatively superficial.

In regard to the distribution of sediment by currents it may be observed, that the rate of subsidence of the finer mud carried down by every great river into the ocean, or of that caused by the rolling of the waves upon a shore, must be extremely slow; for the more minute the separate particles of mud, the more slowly will they sink to the bottom, and the sooner will they acquire what is called their terminal velocity. It is well known that a solid body, descending through a resisting medium, falls by the force of gravity, which is constant, but its motion is resisted by the medium more and more as its velocity increases, until the resistance becomes sufficient to counteract the further increase of velocity. For example, a leaden ball, one inch diameter, falling through air of density as at the earth's surface, will never acquire greater velocity than 260 feet per second, and, in water, its greatest velocity will be 8 feet 6 inches per second. If the diameter of the ball were $\frac{1}{100}$ of an inch, the terminal velocities in air would be 26 feet, and in water ·86 of a foot per second.

Now, every chemist is familiar with the fact, that minute particles descend with extreme slowness through water, the extent of their surface being very great in proportion to their weight, and the resistance of the fluid depending on the amount of surface. A precipitate of sulphate of baryta, for

example, will sometimes require more than five or six hours to subside one inch;* while oxalate and phosphate of lime require nearly an hour to subside about an inch and a half and two inches respectively,† so exceedingly small are the particles of which these substances consist.

When we recollect that the depth of the ocean is supposed frequently to exceed three miles, and that currents run through different parts of that ocean at the rate of four miles an hour, and when at the same time we consider that some fine mud carried away from the mouths of rivers and from sea-beaches, where there is a heavy surf, as well as the impalpable powder showered down by volcanos, may subside at the rate of only an inch per hour, we shall be prepared to find examples of the transportation of sediment over areas of indefinite extent.

* On the authority of Mr. Faraday. † On the authority of Mr. R. Phillips.

CHAPTER XXIII.

IGNEOUS CAUSES.

CHANGES OF THE INORGANIC WORLD, CONTINUED—IGNEOUS CAUSES—DIVISION OF THE SUBJECT—DISTINCT VOLCANIC REGIONS—REGION OF THE ANDES—SYSTEM OF VOLCANOS EXTENDING FROM THE ALEUTIAN ISLES TO THE MOLUCCA AND SUNDA ISLANDS—POLYNESIAN ARCHIPELAGO—VOLCANIC REGION EXTENDING FROM CENTRAL ASIA TO THE AZORES—TRADITION OF DELUGES ON THE SHORES OF THE BOSPHORUS, HELLESPONT, AND GRECIAN ISLES—PERIODICAL ALTERNATION OF EARTHQUAKES IN SYRIA AND SOUTHERN ITALY—WESTERN LIMITS OF THE EUROPEAN REGION—EARTHQUAKES RARER AND MORE FEEBLE AS WE RECEDE FROM THE CENTRES OF VOLCANIC ACTION—EXTINCT VOLCANOS NOT TO BE INCLUDED IN LINES OF ACTIVE VENTS.

WE have hitherto considered the changes wrought, since the times of history and tradition, by the continued action of aqueous causes on the earth's surface; and we have next to examine those resulting from igneous agency. As the rivers and springs on the land, and the tides and currents in the sea, have, with some slight modifications, been fixed and constant to certain localities from the earliest periods of which we have any records, so the volcano and the earthquake have, with few exceptions, continued, during the same lapse of time, to disturb the same regions. But as there are signs, on almost every part of our continent, of great power having been exerted by running water on the surface of the land, and by waves, tides, and currents on cliffs bordering the sea, where, in modern times, no rivers have excavated, and no waves or tidal currents undermined—so we find signs of volcanic vents and violent subterranean movements in places where the action of fire or internal heat has long been dormant. We can explain why the intensity of the force of aqueous causes should be developed in succession in different districts. Currents, for example, tides, and the waves of the

sea, cannot destroy coasts, shape out or silt up estuaries, break through isthmuses, and annihilate islands, form shoals in one place, and remove them from another, without the direction and position of their destroying and transporting power becoming transferred to new localities. Neither can the relative levels of the earth's crust, above and beneath the waters, vary from time to time, as they are admitted to have varied at former periods, and as it will be demonstrated that they still do, without the continents being, in the course of ages, modified, and even entirely altered, in their external configuration. Such events must clearly be accompanied by a complete change in the volume, velocity, and direction of the streams and land floods to which certain regions give passage. That we should find, therefore, cliffs where the sea once committed ravages, and from which it has now retired—estuaries where high tides once rose, but which are now dried up—valleys hollowed out by water, where no streams now flow, is no more than we should expect;—these and similar phenomena are the necessary consequences of physical causes now in operation; and if there be no instability in the laws of nature, similar fluctuations must recur again and again in time to come.

But, however natural it may be that the force of running water in numerous valleys, and of tides and currents in many tracts of the sea, should now be *spent*, it is by no means so easy to explain why the violence of the earthquake and the fire of the volcano should also have become locally extinct at successive periods. We can look back to the time when the marine strata, whereon the great mass of Etna rests, had no existence; and that time is extremely modern in the earth's history. This alone affords ground for anticipating that the eruptions of Etna will one day cease.

> Nec quæ sulfureis ardet fornacibus Ætna
> Ignea semper erit, *neque enim fuit ignea semper*,
> (OVID, *Metam.* lib. xv. 340.)

are the memorable words which are put into the mouth of Pythagoras by the Roman poet, and they are followed by speculations as to the cause of volcanic vents shifting their

positions. Whatever doubts the philosopher expresses as to the nature of these causes, it is assumed, as incontrovertible, that the points of eruption will hereafter vary, *because they have formerly done so*; a principle of reasoning which, as I have endeavoured to show in former chapters, has been too much set at nought by some of the earlier schools of geology, which refused to conclude that great revolutions in the earth's surface are now in progress, or that they will take place hereafter, *because* they have often been repeated in former ages.

Division of the subject.—Volcanic action may be defined to be 'the influence exerted by the heated interior of the earth on its external covering.' If we adopt this definition, without connecting it, as Humboldt has done, with the theory of secular refrigeration, or the cooling down of an original heated and fluid nucleus, we may then class under a general head all the subterranean phenomena, whether of volcanos, or earthquakes, and those insensible movements of the land, by which, as will afterwards appear, large districts may be depressed or elevated, without convulsions. According to this view, I shall consider first, the volcano; secondly, the earthquake; thirdly, the rising or sinking of land in countries where there are no volcanos or earthquakes; fourthly, the probable *causes* of the different changes which result from subterranean agency.

It is a very general opinion that earthquakes and volcanos have a common origin; for both are confined to certain regions, although the subterranean movements are as a rule by no means most violent in the immediate proximity of volcanic vents, especially if the discharge of aeriform fluids and melted rock is made constantly from the same crater. But as there are particular regions, to which both the points of eruption and the movements of great earthquakes are confined, I shall begin by tracing out the geographical boundaries of some of these, that the reader may be aware of the magnificent scale on which the agency of subterranean fire is now simultaneously developed. Over the whole of the vast tracts alluded to, active volcanic vents are distributed at intervals, and most commonly arranged in a linear direction.

Throughout the intermediate spaces there is often abundant evidence that the subterranean fire is at work continuously, for the ground is convulsed from time to time by earthquakes; gaseous vapours, especially carbonic acid gas, are disengaged plentifully from the soil; springs often issue at a very high temperature, and their waves are usually impregnated with the same mineral matters as are discharged by volcanos during eruptions.

When a volcano is isolated like Etna, it is supposed to have opened a communication with the interior by a star-shaped fissure, whereas vents which are linearly arranged imply a long line of dislocation in the earth's crust, analogous to those great lines of rending, upheaval, or dislocation to which the axes of mountain-chains are due. We know that when the side of a great volcanic cone is rent, an open and straight fissure is sometimes formed many miles in length, as was the case on Etna in 1669, when a rent twelve miles long was produced, at the bottom of which incandescent lava was seen. Here and there along the line of such a rent, cones of eruption are thrown up in succession at points where the gaseous matter obtains the freest access to the surface, and has power to force up lava and scoriæ. What is here displayed on a small scale is exhibited in grander dimensions where active volcanos form chains thousands of miles in length. The distances to which trap dikes or the lava which once filled the lower parts of vertical rents can sometimes be traced, is another monument of the same kind of action. Some of the dikes in the north-east of England—Yorkshire, Durham, and Northumberland—for instance, may be followed from 20 to 60 miles in nearly straight lines, and were no doubt at some remote period connected with fissures extending upwards perhaps even to what was then the surface of the earth's crust, whether covered by the sea or atmosphere. M. Alexis Perrey, in his History of Earthquakes, has shown that violent subterranean movements are most frequent along the axes of mountain-chains.

VOLCANIC REGIONS.

Region of the Andes of South America.—Of the great volcanic regions, that of the Andes of South America is one of the best defined; it affords an illustration of the linear arrangement already alluded to, of which there is no good exemplification in Europe, where the most active volcanic vents are isolated. If we turn first to that part of the Cordillera which extends from lat. 2° N. or northward of Quito to lat. 43° S. or southward of Chili, we have, in a space comprehending forty-five degrees of latitude, an alternation on a grand scale of districts of active with those of extinct volcanos, or which, if not spent, have at least been dormant for the last three centuries. How long an interval of rest may entitle us to consider a volcano as entirely extinct is not easily determined; but we know that in Ischia there intervened between two consecutive eruptions a pause of seventeen centuries; and the discovery of America is an event of far too recent a date to allow us even to conjecture whether different portions of the Andes, nearly the whole of which are subject to earthquakes, may not experience alternately a cessation and renewal of eruptions. Nor does the linear series seem to end even with the southern limits of the Cordillera, for we can scarcely doubt that the Fuegian volcanos in lat. 54° 30′ S., and those of South Shetland, lat. 61° S., belong to the same chain.

The principal line of active vents which have been seen in eruption in the Andes extends from lat. 43° 28′ S.; or, from Yantales, opposite the isle of Chiloe, to Coquimbo, in lat. 30° S.; to these thirteen degrees of latitude succeed more than eight degrees, in which no recent volcanic eruptions have been observed. We then come to the volcanos of Bolivia and Peru, reaching six degrees from S. to N., or from lat. 21° S. to lat. 15° S. Between the Peruvian volcanos and those of Quito, another space intervenes of no less than fourteen degrees of latitude, said to be free from volcanic action so far as yet known. The volcanos of Quito then succeed, beginning about 100 geographical miles south of

the equator, and continuing for about 130 miles north of it, when there occurs another undisturbed interval of more than six degrees of latitude, after which we arrive at the volcanos of Guatemala or Central America, north of the Isthmus of Panama.*

Having thus traced out the line from south to north, I may first state, in regard to the numerous vents of Chili, that the volcanos of Yantales and Osorno were in eruption during the great earthquake of 1835, at the same moment that the land was shaken in Chiloe, and in some parts of the Chilian coast permanently upheaved; whilst at Juan Fernandez, at the distance of no less than 720 geographical miles from Yantales, an eruption took place beneath the sea. We have thus proofs of a great subterranean disturbance extending simultaneously over an area about 900 miles (60 to a degree) north and south, and in one part at least 600 due east and west. Some of the volcanos of Chili are of great height, as that of Antuco, in lat. 37° 40′ S., the summit of which is at least 16,000 feet above the sea. From the flanks of this volcano, at a great height, immense currents of lava have issued, one of which flowed in the year 1828. This event is said to be an exception to the general rule; few volcanos in the Andes, and none of those in Quito, having been seen in modern times to pour out lava, but having merely ejected vapour or scoriæ.

Both the basaltic (or augitic) lavas, and those of the felspathic class, occur in Chili and other parts of the Andes; but the volcanic rocks of the felspathic family are said by Von Buch to be generally not trachyte, but a rock which has been called andesite, or a mixture of augite and albite. The last-mentioned mineral contains soda instead of the potash found in common felspar.

The volcano of Rancagua, lat. 34° 15′ S., is said to be always throwing out ashes and vapours like Stromboli, a proof of the permanently heated state of certain parts of the interior of the earth below. A year rarely passes in Chili without some slight shocks of earthquakes, and in certain districts not a month. Those shocks which come from the

* See Von Buch's Description of Canary Islands (Paris, ed. 1836) for a valuable sketch of the principal volcanos of the globe.

side of the ocean are the most violent, and the same is said to be the case in Peru. The town of Copiapo was laid waste by this terrible scourge in the years 1773, 1796, and 1819, or in both cases after regular intervals of twenty-three years. There have, however, been other shocks in that country in the periods intervening between the dates above mentioned, although probably all less severe, at least on the exact site of Copiapo. The evidence against a regular recurrence of volcanic convulsions at stated periods is so strong as a general fact, that we must be on our guard against attaching too much importance to a few striking but probably accidental coincidences. Among these last might be adduced the case of Lima, violently shaken by an earthquake on the 17th of June, 1578, and again on the very same day, 1678; or the eruptions of Coseguina in the year 1709 and 1809, which are the only two recorded of that volcano previous to that of 1835.*

Of the permanent upheaval of land after earthquakes in Chili, I shall have occasion to speak in the next chapter, when it will also be seen that great shocks often coincide with eruptions, either submarine, or from the cones of the Andes, showing the connection between the force which elevates continents with that which causes volcanic outbursts.†

The space between Chili and Peru, in which no volcanic action has been observed, is 150 nautical leagues from south to north. It is, however, as Von Buch observes, that part of the Andes which is least known, being thinly peopled, and in some parts entirely desert. The volcanos of Peru rise from a lofty platform to vast heights from 17,000 to 20,000 feet above the level of the sea. The lava which has issued from Viejo, lat. 16° 55′ S., accompanied by pumice, is composed of a mixture of crystals of albitic felspar, hornblende, and mica, a rock which has been considered as one of the varieties of andesite. Some tremendous earthquakes which have visited Peru in modern times will be mentioned in a subsequent chapter.

The volcanos of Quito, occurring between the second

* Darwin, Geol. Trans. 2d series, vol. v. p. 612. † Ibid. p. 606.

degree of south and the third degree of north latitude, rise to vast elevations above the sea, many of them being between 14,000 and 18,000 feet high. The Indians of Lican have a tradition that the mountain called L'Altar, or Capac Urcu, which means 'the chief,' was once the highest of those near the equator, being higher than Chimborazo; but in the reign of Ouainia Abomatha, before the discovery of America, a prodigious eruption took place, which lasted eight years, and broke it down. The fragments of trachyte, says M. Boussingault, which once formed the conical summit of this celebrated mountain, are at this day spread over the plain.* Cotopaxi is the most lofty of all the South American volcanos which have been in a state of activity in modern times, its height being 18,858 feet; and its eruptions have been more frequent and destructive than those of any other mountain. It is a perfect cone, usually covered with an enormous bed of snow, which has, however, been sometimes melted suddenly during an eruption; as in January 1803, for example, when the snows were dissolved in one night.

Deluges are often caused in the Andes by the liquefaction of great masses of snow, and sometimes by the rending open, during earthquakes, of subterranean cavities filled with water. In these inundations fine volcanic sand, loose stones, and other materials which the water meets with in its descent, are swept away, and a vast quantity of mud, called 'moya,' is thus formed and carried down into the lower regions. Mud derived from this source descended, in 1797, from the sides of Tunguragua in Quito, and filled valleys a thousand feet wide to the depth of six hundred feet, damming up rivers and causing lakes. In these currents and lakes of moya, thousands of small fish are sometimes enveloped, which, according to Humboldt, have lived and multiplied in subterranean cavities. So great a quantity of these fish were ejected from the volcano of Imbaburu in 1691, that fevers, which prevailed at the period, were attributed to the effluvia arising from the putrid animal matter.

In Quito, many important revolutions in the physical features of the country are said to have resulted, within the

* Bull. de la Soc. Géol. de France, 2d Sér. tom. vi. p. 55.

memory of man, from the earthquakes by which it has been convulsed. M. Boussingault declares his belief, that if a full register had been kept of all the convulsions experienced here and in other populous districts of the Andes, it would be found that the trembling of the earth had been incessant. The frequency of the movement, he thinks, is not due to volcanic explosions, but to the continual falling in of masses of rock which have been fractured and upheaved in a solid form at a comparatively recent epoch; but a longer series of observations would be requisite to confirm this opinion. According to the same author, the height of several mountains of the Andes has diminished in modern times.*

The great crest or cordillera of the Andes is depressed at the Isthmus of Panama to about 1,000 feet above the sea-level, and the watershed between the two seas near the Gulf of San Miguel is only 150 feet high. What some geographers regard as a continuation of that chain in Central America lies to the east of a series of volcanos, many of which are active in the provinces of Pasto, Popayan, and Guatemala. Coseguina, on the south side of the Gulf of Fonseca, was in eruption in January 1835, and some of its ashes fell at Truxillo on the shores of the Gulf of Mexico. What is still more remarkable, on the same day, at Kingston in Jamaica, the same shower of ashes fell, having been carried by an upper counter-current against the regular east wind which was then blowing. Kingston is about 700 miles distant from Coseguina, and these ashes must have been more than four days in the air, having travelled 170 miles a day. Eight leagues to the southward of the crater, the ashes covered the ground to the depth of three yards and a half, destroying the woods and dwellings. Thousands of cattle perished, their bodies being in many instances one mass of scorched flesh. Deer and other wild animals sought the towns for protection; many birds and quadrupeds were found suffocated in the ashes, and the neighbouring streams were strewed with dead fish.† Such facts throw light on geological monuments, for in the ashes thrown out at remote

* Bull. de la Soc. Géol. de France, tom. vi. p. 56.

† Caldcleugh, Phil. Trans. 1836, p. 27.

periods from the volcanos of Auvergne, now extinct, we find the bones and skeletons of lost species of quadrupeds.

Mexico.—The great volcanic chain, after having thus pursued its course for several thousand miles from south to north, sends off a branch in a new direction in Mexico, in the parallel of the city of that name, and is prolonged in a great platform, between the eighteenth and twenty-second degrees of north latitude. Five active volcanos traverse Mexico from west to east—Tuxtla, Orizaba, Popocatepetl, Jorullo, and Colima. Jorullo, which is in the centre of the great platform, is no less than 120 miles from the nearest ocean—an important circumstance, as showing that the proximity of the sea is not a necessary condition, although certainly a very general characteristic, of the position of active volcanos. The extraordinary eruption of this mountain, in 1759, will be described in the sequel. If the line which connects these five vents be prolonged in a westerly direction, it cuts the volcanic group of islands called the Isles of Revillagigedo, in the Pacific.

To the north of Mexico there are said to be three, or according to some, five volcanos in the peninsula of California; and a volcano is reported to have been in eruption on the N.W. coast of America, near the Colombia River, lat. 45° 37′ N.

West Indies.—To return to the Andes of Quito, Von Buch was inclined to believe that if we were better acquainted with the region to the east of the Madalena, and with New Granada and the Caraccas, we might find the volcanic chain of the Andes to be connected with that of the West Indian, or Caribbee Islands. The truth of this conjecture has almost been set at rest by the eruption, in 1848, of the volcano of Zamba in New Granada, at the mouth of the river Madalena.*

Of the West Indian Islands there are two parallel series, the one to the west, which are all volcanic, and which rise to the height of several thousand feet; the other to the east, for the most part composed of calcareous rocks, and very low. In the former or volcanic series, are Granada, St. Vin-

* Comptes Rendus, 1849, vol. xxix. p. 531.

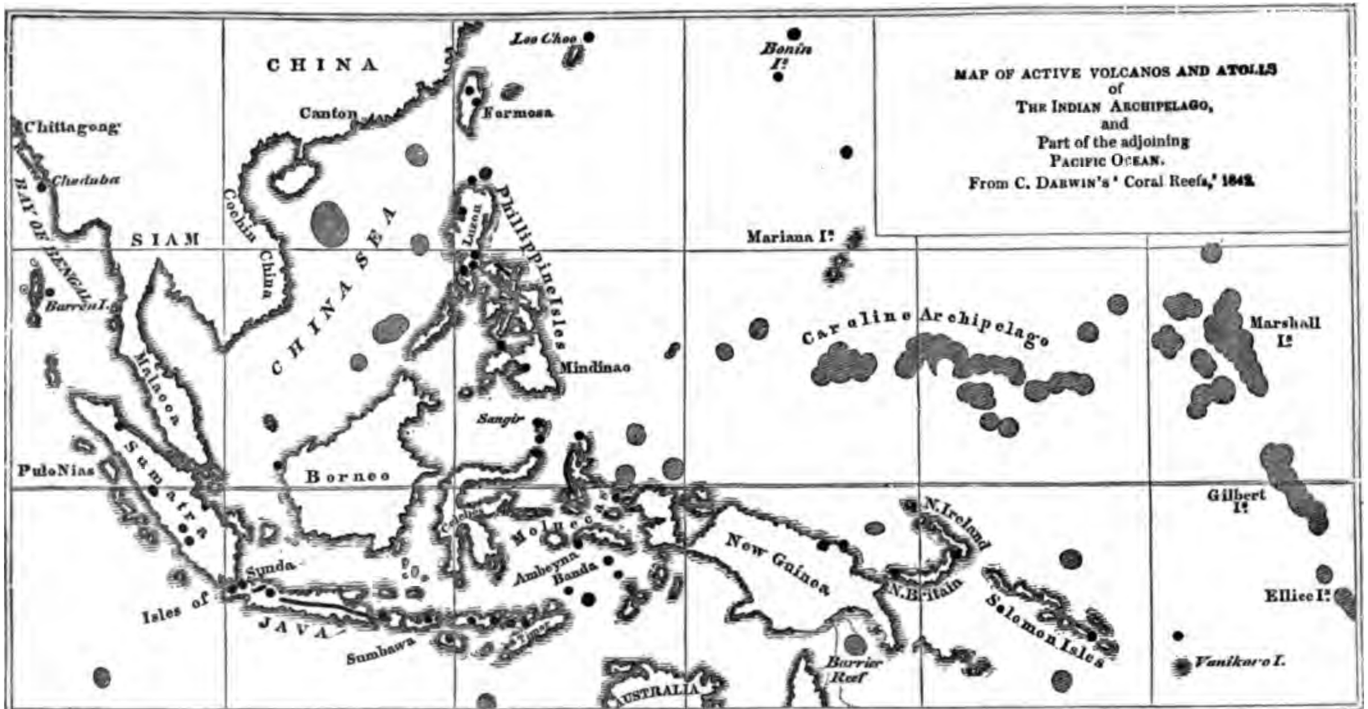
cent, St. Lucia, Martinique, Dominica, Guadaloupe, Montserrat, Nevis, and St. Eustace. In the calcareous chain are Tobago, Barbadoes, Mariegallaute, Grandeterre, Desirade, Antigua, Barbuda, St. Bartholomew, and St. Martin. The most considerable eruptions in modern times have been those of St. Vincent. Great earthquakes have agitated St. Domingo, as will be seen in the thirtieth chapter.

I have before mentioned (p. 459) the violent earthquake which in 1812 convulsed the valley of the Mississippi at New Madrid, for the space of 300 miles in length, of which more will be said in the twenty-eighth chapter. This happened exactly at the same time as the great earthquake of Caraccas, so that it is possible that these two points are parts of one subterranean volcanic region. The island of Jamaica, with a tract of the contiguous sea, has often experienced tremendous shocks; and these are frequent along a line extending from Jamaica to St. Domingo and Porto Rico.

Thus it will be seen that, without taking account of the West Indian and Mexican branches, a linear train of volcanos and tracts shaken by earthquakes may be traced from the island of Chiloe and opposite coast to Mexico, or even perhaps to the mouth of the Columbia River—a distance upon the whole as great as from the pole to the equator. In regard to the western limits of the region, they lie deep beneath the waves of the Pacific, and must continue unknown to us. On the east they are not prolonged to a great distance, except where they include the West Indian Islands; for there seem to be no indications of volcanic eruptions in Buenos Ayres, Brazil, and the United States of North America east of the Rocky Mountains. In California, Oregon, and north-west America, ten or twelve volcanos are mentioned.

Volcanic region from the Aleutian Isles to the Moluccas and Isles of Sunda.—On a scale, which equals, or surpasses, that of the Andes, is another line of volcanic action, which commences, on the north, with the Aleutian Isles in Russian America, and extends, first in a westerly direction for nearly 200 geographical miles, and then southwards, with a few interruptions, throughout a space of between sixty and seventy

Fig. 65.



Active volcanos. Trains of active volcanos. Areas of subsidence containing atolls or coral islands with lagoons.

degrees of latitude to the Moluccas, where it sends off a branch to the south-east, while the principal train continues westerly through Sumbawa and Java to Sumatra, and then in a north-westerly direction to the Bay of Bengal.* This volcanic line, observes Von Buch, may be said to follow throughout its course the external border of the continent of Asia; while the branch which has been alluded to as striking south-east from the Moluccas, passes from New Guinea to New Zealand, conforming, though somewhat rudely, to the outline of Australia.†

The connection, however, of the New Guinea volcanos with the line in Java (as laid down in Von Buch's map) is not clearly made out. By consulting Darwin's map of coral reefs and active volcanos,‡ the reader will see that we might almost with equal propriety include the Mariana and Bonin volcanos in a band with New Guinea. Or if we allow so much latitude in framing zones of volcanic action, we must also suppose the New Hebrides, Solomon Isles, and New Ireland (see map, fig. 65, p. 586) to constitute one line with the New Hebrides, which lie to the south of the same map.

The northern extremity of the volcanic region of Asia, as described by Von Buch, is on the borders of Cook's Inlet, north-east of the Peninsula of Alaska, where one volcano, in about the sixtieth degree of latitude, is said to be 14,000 feet high. In Alaska itself are cones of vast height, which have been seen in eruption, and which are covered for two thirds of their height downwards with perpetual snow. The summit of the loftiest peak is truncated, and is said to have fallen in during an eruption in 1786. From Alaska the line is continued through the Aleutian or Fox Islands to Kamtschatka. In the Aleutian Archipelago eruptions are frequent, and about thirty miles to the north of Unalaska, near the Isle of Umnack, a new island was formed in 1796. It was first observed after a storm, at a point in the sea from which a column of smoke had been seen to rise. Flames then issued from the new islet which illuminated the country for ten miles round;

* See map of volcanic lines in Von Buch's work on the Canaries.

† Von Buch. ibid. 409.

‡ Darwin, Structure and Distrib. of Coral Reefs, &c. London, 1842. In the annexed map, fig. 65, I have copied with permission a small part of the valuable map accompanying that work.

a frightful earthquake shook the new-formed cone, and showers of stones were thrown as far as Umnack. The eruption continued for several months, and eight years afterwards, in 1804, when it was explored by some hunters, the soil was so hot in some places that they could not walk on it. According to Langsdorf and others, this new island, which is now several thousand feet high and two or three miles in circumference, has been continually found to have increased in size when successively visited by different travellers; but we have no accurate means of determining how much of its growth, if any, has been due to upheaval, or how far it has been exclusively formed by the ejection of ashes and streams of lava. It seems, however, to be well attested that earthquakes of the most terrific description agitate and alter the bed of the sea and surface of the land throughout this tract.

The line is continued in the southern extremity of the Peninsula of Kamtschatka, where, according to Dittmar, there are twelve active and twenty-six extinct volcanic cones. The largest and most active of these is Klutschew, lat. 56° 3′ N., which rises at once from the sea to the prodigious height of 15,000 feet. Within 700 feet of the summit, Erman saw, in 1829, a current of lava, emitting a vivid light, flow down the north-west side to the foot of the cone. Large quantities of ice and snow opposed for a time a barrier to the lava, until at length the fiery torrent overcame, by its heat and pressure, this obstacle, and poured down the mountain side with a frightful noise, which was heard for a distance of more than fifty miles.*

Mont Blanc is 15,760 feet high, but a flow of lava from its summit to the base in the valley of Chamouni would give a very inadequate idea of the descent of the Kamtschatka current, because Chamouni is 3,500 feet above the level of the sea.†

The Kurile chain of islands constitutes the prolongation of the Kamtschatka range, where a train of volcanic mountains, nine of which are known to have been in eruption, trends in a

* Von Buch. Descrip. des Iles Canar. p. 450, who cites Erman and others.

† For later eruptions in the Alaska, Kamtschatka, and Kurile region, see Alexis Perrey, Soc. Imp. de Lyon, 1863

southerly direction. The line is then continued to the south-west in the great island of Jesso, and again in Nipon, the principal of the Japanese group. It then extends by Loo Choo and Formosa to the Philippine Islands, and thence by Sangir and the north-eastern extremity of Celebes to the Moluccas (see map, fig. 65). Afterwards it passes westward through Sumbawa to Java.

There are said to be thirty-eight considerable volcanos in Java, some of which are more than 10,000 feet high. They are remarkable for the quantity of sulphur and sulphureous vapours which they discharge. They rarely emit lava, but rivers of mud issue from them, like the moya of the Andes of Quito. The memorable eruption of Galongoon, in 1822, will be described in the twenty-sixth chapter. The crater of Taschem, at the eastern extremity of Java, contains a lake strongly impregnated with sulphuric acid, a quarter of a mile long, from which a river of acid water issues, which supports no living creature, nor can fish live in the sea near its confluence. There is an extinct crater near Batur, called Guevo Upas, or the Valley of Poison, about half a mile in circumference, which is justly an object of terror to the inhabitants of the country. Every living being which penetrates into this valley falls down dead, and the soil is covered with the carcasses of tigers, deer, birds, and even the bones of men; all killed by the abundant emanations of carbonic acid gas, by which the bottom of the valley is filled.

In another crater in this land of wonders, near the volcano of Talaga Bodas, we learn from Mr. Reinwardt, that the sulphureous exhalations have killed tigers, birds, and innumerable insects; and the soft parts of these animals, such as fibres, muscles, nails, hair, and skin, are very well preserved, while the bones are corroded, and entirely destroyed.

We learn from observations made in 1844, by Mr. Jukes, that a recent tertiary formation composed of limestone and resembling the coral rock of a fringing reef, clings to the flanks of all the volcanic islands from the east end of Timor to the west end of Java. These modern calcareous strata are often white and chalk-like, sometimes 1,000 feet and upwards above the sea, regularly stratified in thick horizontal

beds, and they show that there has been a general elevation of these islands at a comparatively modern period.*

The same linear arrangement which is observed in Java holds good in the volcanos of Sumatra, some of which are of great height, as Berapi, which is more than 12,000 feet above the sea, and is continually emitting vapour. Hot springs are abundant at its base. The volcanic line then inclines slightly to the north-west, and points to Barren Island, lat. 12° 15′ N., in the Bay of Bengal; a volcano often observed to emit smoke and vapours, and from which lava has proceeded since 1780 (see below, Chap. XXVII.). The volcanic train then extends, according to Dr. Macclelland, to the island of Narcondam, lat. 13° 22′ N., which is a cone seven or eight hundred feet high, rising from deep water, and said to present signs of lava currents descending from the crater to the base. Afterwards the train stretches in the same direction to the volcanic island of Ramree, about lat. 19° N., and the adjoining island of Cheduba, which is represented in old charts as a burning mountain. Thus we arrive at the Chittagong coast, which in 1672 was convulsed by a tremendous earthquake (see Chap. XXX.).†

To enumerate all the volcanic regions of the Indian and Pacific oceans would lead me far beyond the proper limits of this treatise; but it will appear in the last chapter of this work, when coral reefs are treated of, that the islands of the Pacific consist alternately of linear groups of two classes, the one lofty, and containing active volcanos, and marine strata above the sea-level, and which have been undergoing upheaval in modern times; the other very low, consisting of reefs of coral, usually with lagoons in their centres, and in which there is evidence of a gradual subsidence of the ground. The extent and direction of these parallel volcanic bands has been depicted with great care by Darwin in his map before cited (p. 587).

The most remarkable theatre of volcanic activity in the Northern Pacific—or, perhaps, in the whole world—occurs

* Paper read at meeting of Brit. Assoc. Southampton, Sept. 1846.

† Macclelland, Report on Coal and Min. Resources of India. Calcutta, 1838.

in the Sandwich Islands, which have been admirably treated of in a work published by Mr. Dana in 1849.*

Volcanic region from Central Asia to the Azores.—Another great region of subterranean disturbance is that which has been imagined to extend through a large part of Central Asia to the Azores, that is to say, from China and Tartary through Lake Aral and the Caspian to the Caucasus and the countries bordering the Black Sea, then again through part of Asia Minor to Syria, and westward to the Grecian Islands, Greece, Naples, Sicily, the southern part of Spain, Portugal, and the Azores. The breaks in this supposed continuous series of volcanic disturbances are of such extent that the connection as a linear group cannot be insisted on, but it may be useful in helping us to remember the geographical limits within which certain volcanos and earthquakes of historical date have been witnessed. Respecting the eastern extremity of this line in China, we have little information, but many violent earthquakes are known to have occurred there. The volcano said to have been in eruption in the seventh century in Central Tartary is situated on the northern declivity of the Celestial Mountains, not far distant from the large lake called Issikoul; and Humboldt mentions other vents and solfataras in the same quarter, which are all worthy of notice, as being far more distant from the ocean (260 geographical miles) than any other known points of eruption on the globe.

We find on the western shores of the Caspian, in the country round Baku, a tract called the Field of Fire, which continually emits inflammable gas, while springs of naphtha and petroleum occur in the same vicinity, as also mud volcanos (see Chap. XXVII.). Syria and Palestine abound in volcanic appearances, and very extensive areas have been shaken, at different periods, with great destruction of cities and loss of lives. Continual mention is made in history of the ravages committed by earthquakes in Sidon, Tyre, Berytus, Laodicea, and Antioch, and in the Island of Cyprus.

* Geology of the American Exploring Expedition. See also Lyell's Elements of Geology, 'Sandwich I. Volcanos'—Index.

The country around the Dead Sea exhibits in some spots layers of sulphur and bitumen, forming a superficial deposit, supposed by Mr. Tristram to be of volcanic origin. A district near Smyrna, in Asia Minor, was termed by the Greeks Catacecaumene, 'or 'the burnt up,' where there is a large arid territory, without trees, and with a cindery soil.* This country was visited in 1841 by Mr. W. J. Hamilton, who found in the valley of the Hermus perfect cones of scoriæ, with lava-streams, like those of Auvergne, conforming to the existing river-channels, and with their surface undecomposed.†

Grecian Archipelago.—Proceeding westwards, we reach the Grecian Archipelago, where Santorin, afterwards to be described, is the grand centre of volcanic action (Vol. II. Chap. XXVII.).

It was Von Buch's opinion that the volcanos of Greece were arranged in a line running N.N.W. and S.S.E., and that they afforded the only example in Europe of active volcanos having a linear direction; but M. Virlet, on the contrary, announces as the result of his investigations, made during the French expedition to the Morea in 1829, that there is no one determinate line of direction for the volcanic phenomena in Greece, whether we follow the points of eruptions, or the earthquakes, or any other signs of igneous agency.‡

Macedonia, Thrace, and Epirus have always been subject to earthquakes, and the Ionian Isles are continually convulsed.

Respecting Southern Italy, Sicily, and the Lipari Isles, it is unnecessary to enlarge here, as I shall have occasion again to allude to them. I may mention, however, that a band of volcanic action has been traced by Dr. Daubeny across the Italian Peninsula, from Ischia to Mount Vultur, in Apulia, the commencement of the line being found in the hot springs of Ischia, after which it is prolonged through Vesuvius to the Lago d'Ansanto, where gases similar to those of Vesuvius

* Strabo, ed. Fal. p. 900.

† Researches in Asia Minor, vol. ii. p. 39.

‡ Virlet, Bulletin de la Soc. Géol. de France, tom. iii. p. 109.

are evolved. Its farther extension strikes Mount Vultur, a lofty cone composed of tuff and lava, from one side of which carbonic acid and sulphuretted hydrogen are emitted.*

Traditions of deluges.—The traditions which have come down to us from remote ages of great inundations said to have happened in Greece and on the confines of the Grecian settlements, had doubtless their origin in a series of local catastrophes, caused principally by earthquakes. The frequent migrations of the earlier inhabitants, and the total want of written annals long after the settlement of each country, make it impossible for us at this distance of time to fix either the true localities or probable dates of these events. The first philosophical writers of Greece were, therefore, as much at a loss as ourselves to offer a reasonable conjecture on these points, or to decide how many catastrophes might sometimes have become confounded in one tale, or how much this tale may have been amplified, in after times, or obscured by mythological fiction. The floods of Ogyges and Deucalion are commonly said to have happened before the Trojan war; that of Ogyges more than seventeen, and that of Deucalion more than fifteen, centuries before our era. As to the Ogygian flood, it is generally described as having laid waste Attica, and was referred by some writers to a great overflowing of rivers, to which cause Aristotle also attributed the deluge of Deucalion, which, he says, affected Hellas only, or the central part of Thessaly. Others imagined the same event to have been due to an earthquake, which threw down masses of rock, and stopped up the course of the Peneus in the narrow defile between mounts Ossa and Olympus.

As to the deluge of Samothrace, which is generally referred to a distinct date, it appears that the shores of that small island and the adjoining mainland of Asia were inundated by the sea. Diodorus Siculus says that the inhabitants had time to take refuge in the mountains, and save themselves by flight; he also relates, that long after the event the fishermen of the island drew up in their nets the capitals of columns, 'which were the remains of cities submerged

* Daubeny on Mount Vultur. Ashmolean Memoirs. Oxford, 1835.

by that terrible catastrophe.' * These statements scarcely leave any doubt that there occurred, at the period alluded to, earthquakes and inroads of the sea accompanied by a subsidence of the coast. It is not impossible that the story of the bursting of the Black Sea through the Thracian Bosphorus into the Grecian Archipelago, which accompanied, and, as some say, caused the Samothracian deluge, may have reference to a wave or succession of waves, raised in the Euxine by the same convulsion.

We know that subterranean movements and volcanic eruptions are often attended not only by incursions of the sea, but also by violent rains, and the complete derangement of the river drainage of the inland country, and by the damming up of the outlets of lakes by landslips, or obstructions in the courses of subterranean rivers, such as abound in Thessaly and the Morea. We need not therefore be surprised at the variety of causes assigned for the traditional floods of Greece, by Herodotus, Aristotle, Diodorus, Strabo, and others. As to the area embraced, had all the Grecian deluges occurred simultaneously, instead of being spread over many centuries, and had they, instead of being extremely local, reached at once from the Euxine to the south-western limit of the Peloponnesus, and from Macedonia to Rhodes, the devastation would still have been more limited than that already alluded to p. 581, which visited Chili in 1835, when a volcanic eruption broke out in the Andes, opposite Chiloe, and another at Juan Fernandez, distant 720 geographical miles, at the same time that several lofty cones in the Cordillera, 400 miles to the eastward of that island, threw out vapour and ignited matter. Throughout a great part of the space thus recently shaken in South America, cities were laid in ruins, or the land was permanently upheaved, or mountainous waves rolled inland from the Pacific.

Periodical alternation of earthquakes in Syria and Southern Italy.—It has been remarked by Von Hoff, that from the commencement of the thirteenth to the latter half of the seventeenth century, there was an almost entire cessation of

* Book v. ch. xlvi.—See Letter of M. Virlet, Bulletin de la Soc. Géol. de France, tom. ii. p. 341.

earthquakes in Syria and Judea; and, during this interval of quiescence, the Archipelago, together with part of the adjacent coast of Asia Minor, as also Southern Italy and Sicily, suffered greatly from earthquakes; while volcanic eruptions were unusually frequent in the same regions. A more extended comparison, also, of the history of the subterranean convulsions of these tracts seems to confirm the opinion, that a violent crisis of commotion never visits both at the same time. It is impossible for us to declare, as yet, whether this phenomenon is constant in this and other regions, because we can rarely trace back a connected series of events farther than a few centuries; but it is well known that, where numerous vents are clustered together within a small area, as in many archipelagos for instance, two of them are never in violent eruption at once. If the action of one becomes very great for a century or more, the others assume the appearance of spent volcanos. It is, therefore, not improbable that separate provinces of the same great range of volcanic fires may hold a relation to one deep-seated focus, analogous to that which the apertures of a small group bear to some more superficial rent or cavity. Thus, for example, we may conjecture that, at a comparatively small distance from the surface, Ischia and Vesuvius mutually communicate with certain fissures, and that each affords relief alternately to elastic fluids and lava there generated. So we may suppose Southern Italy and Syria to be connected, at a much greater depth, with a lower part of the very same system of fissures; in which case any obstruction occurring in one duct may have the effect of causing almost all the vapour and melted matter to be forced up the other, and if they cannot get vent, they may be the cause of violent earthquakes. Some objections advanced against this doctrine that 'volcanos act as safety-valves,' will be considered in the sequel.*

The north-eastern portion of Africa, including Egypt, which lies six or seven degrees south of the volcanic line already traced, has been almost always exempt from earthquakes; but the north-western portion, especially Fez and Morocco, which fall within the line, suffer greatly from time

* See Vol. II. Ch. XXXII., *Cause of Volcanic Eruptions.*

to time. The southern part of Spain, and also of Portugal, have generally been exposed to the same scourge simultaneously with Northern Africa. The provinces of Malaga, Murcia, and Granada, and in Portugal the country round Lisbon, are recorded at several periods to have been devastated by great earthquakes. It will be seen, from Michell's account of the great Lisbon shock in 1755, that the first movement proceeded from the bed of the ocean ten or fifteen leagues from the coast. So late as February 2, 1816, when Lisbon was vehemently shaken, two ships felt a shock in the ocean west from Lisbon; one of them at the distance of 120, and the other 262 French leagues from the coast *—a fact which is more interesting, because a line drawn through the Grecian Archipelago, the volcanic region of Southern Italy, Sicily, Southern Spain, and Portugal, will, if prolonged westward through the ocean, strike the volcanic group of the Azores, which may possibly therefore have a submarine connection with the European line.

In regard to the volcanic system of Southern Europe, it may be observed, that there is a central tract where the greatest earthquakes prevail, in which rocks are shattered, mountains rent, the surface elevated or depressed, and cities laid in ruins. On each side of this line of greatest commotion there are parallel bands of country where the shocks are less violent. At a still greater distance (as in Northern Italy, for example, extending to the foot of the Alps), there are spaces where the shocks are much rarer and more feeble, yet possibly of sufficient force to cause, by continued repetition, some appreciable alteration in the external form of the earth's crust. Beyond these limits, again, all countries are liable to slight tremors, at distant intervals of time, when some great crisis of subterranean movement agitates an adjoining volcanic region; but these may be considered as mere vibrations, propagated mechanically through the external covering of the globe, as sounds travel almost to indefinite distances through the air. Shocks of this kind have been felt in England, Scotland, Northern France, and Germany—particularly during the Lisbon earthquake. But these countries cannot,

* Verneur, Journal des Voyages, tom. iv. p. 111.—Von Hoff, vol. ii. p. 275.

on this account, be supposed to constitute parts of the southern volcanic region, any more than the Shetland and Orkney Islands can be considered as belonging to the Icelandic circle, because the sands ejected from Hecla have been wafted thither by the winds.

Besides the continuous spaces of subterranean disturbance, of which we have merely sketched the outline, there are other disconnected volcanic groups of which several will be mentioned hereafter.

Lines of active and extinct volcanos not to be confounded.— We must always be careful to distinguish between lines of extinct and active volcanos, even where they appear to run in the same direction; for ancient and modern systems may interfere with each other. Already, indeed, we have proof that this is the case; so that it is not by geographical position, but by reference to the species of organic beings alone, whether aquatic or terrestrial, whose remains occur in beds interstratified with lavas, that we can clearly distinguish the relative age of volcanos of which no eruptions are recorded. Had Southern Italy been known to civilised nations for as short a period as America, we should have had no record of eruptions in Ischia; yet we might have assured ourselves that the lavas of that isle had flowed since the Mediterranean was inhabited by the species of testacea now living in the Neapolitan seas. With this assurance, it would not have been rash to include the numerous vents of that island in the modern volcanic group of Campania.

On similar grounds we may infer, without much hesitation, that the eruptions of Etna, and the modern earthquakes of Calabria, are a continuation of that action which, at a somewhat earlier period, produced the submarine lavas of the Val di Noto in Sicily. But, on the other hand, the lavas of the Euganean Hills and the Vicentin, although not wholly beyond the range of earthquakes in Northern Italy, must not be confounded with any existing volcanic system; for when they flowed, the seas were inhabited by animals of the Eocene period, almost all of them distinct from those now known to live, whether in the Mediterranean or other parts of the globe.

CHAPTER XXIV.

VOLCANIC DISTRICT OF NAPLES.

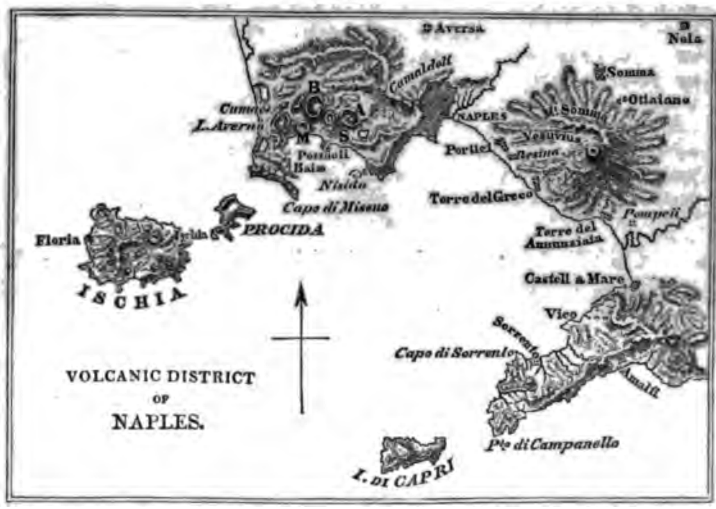
HISTORY OF THE VOLCANIC ERUPTIONS IN THE DISTRICT ROUND NAPLES—EARLY CONVULSIONS IN THE ISLAND OF ISCHIA—NUMEROUS CONES THROWN UP THERE—LAKE AVERNUS—THE SOLFATARA—RENEWAL OF THE ERUPTIONS OF VESUVIUS, A.D. 79.—PLINY'S DESCRIPTION OF THE PHENOMENA—HIS SILENCE RESPECTING THE DESTRUCTION OF HERCULANEUM AND POMPEII—SUBSEQUENT HISTORY OF VESUVIUS—LAVA DISCHARGED IN ISCHIA IN 1302—PAUSE IN THE ERUPTIONS OF VESUVIUS—MONTE NUOVO THROWN UP—UNIFORMITY OF THE VOLCANIC OPERATIONS OF VESUVIUS AND PHLEGRÆAN FIELDS IN ANCIENT AND MODERN TIMES.

I SHALL next give a sketch of the history of some of the volcanic vents dispersed throughout the great regions before described, and consider the composition and arrangement of their lavas and ejected matter. The only volcanic region known to the ancients was that of the Mediterranean; and even of this they have transmitted to us very imperfect records relating to the eruptions of the three principal districts, namely, that round Naples, that of Sicily and its isles, and that of the Grecian Archipelago. By far the most connected series of records throughout a long period relates to the first of these provinces; and these cannot be too attentively considered, as much historical information is indispensable in order to enable us to obtain a clear view of the connection and alternate mode of action of the different vents in a single volcanic group.

Early convulsions in the Island of Ischia.—The Neapolitan volcanos extend from Vesuvius, through the Phlegræan Fields, to Procida and Ischia, in a somewhat linear arrangement, ranging from the north-east to the south-west, as will be seen in the annexed map of the volcanic district of Naples (fig. 66). Within the space above limited, the volcanic force

is sometimes developed in single eruptions from a considerable number of irregularly scattered points; but a great part of its action has been confined to one principal and habitual vent, Vesuvius or Somma. Before the Christian era, from the remotest periods of which we have any tradition, this principal vent was in a state of inactivity. But terrific convulsions then took place from time to time in Ischia (Pithecusa), and seem to have extended to the neighbouring isle of Procida (Prochyta); for Strabo* mentions a story of

Fig. 66.



A. Astroni. B. Monte Barbaro. M. Monte Nuovo. S. The Solfatara.

Procida having been torn asunder from Ischia; and Pliny† derives its name from its having been poured forth by an eruption from Ischia.

The present circumference of Ischia along the water's edge is eighteen miles, its length from west to east about five, and its breadth from north to south three miles. Several Greek colonies which settled there before the Christian era were compelled to abandon it in consequence of the violence of the eruptions. First the Erythræans, and afterwards the Chal-

* Lib. v. † Nat. Hist. lib. iii. c. 6.

cidians, are mentioned as having been turned out by earthquakes and igneous exhalations. A colony was afterwards established by Hiero, king of Syracuse, about 380 years before the Christian era; but when they had built a fortress, they were compelled by an eruption to fly, and never again returned. Strabo tells us that Timæus recorded a tradition, that, a little before his time, Epomeus, the principal mountain in the centre of the island, vomited fire during great earthquakes; that the land between it and the coast had ejected much fiery matter, which flowed into the sea, and that the sea receded for the distance of three stadia, and then returning, overflowed the island. This eruption is supposed by some to have been that which formed the crater of Monte Corvo on one of the higher flanks of Epomeo, above Foria, the lava-current of which may still be traced, by aid of the scoriæ on its surface, from the crater to the sea.

To one of the subsequent eruptions in the lower parts ot the isle, which caused the expulsion of the first Greek colony, Monte Rotaro has been attributed, and it bears every mark of recent origin. The cone, which I examined in 1828, is remarkably perfect, and has a crater on its summit precisely resembling that of Monte Nuovo near Naples; but the hill is larger, and resembles some of the more considerable cones of single eruption near Clermont in Auvergne, and, like some of them, it has given vent to a lava-stream at its base, instead of its summit. A small ravine swept out by a torrent exposes the structure of the cone, which is composed of innumerable inclined and slightly undulating layers of pumice, scoriæ, white lapilli, and enormous angular blocks of trachyte. These last have evidently been thrown out by violent explosions, like those which in 1822 launched from Vesuvius a mass of augitic lava, of many tons' weight, to the distance of three miles, which fell in the garden of Prince Ottajano. The cone of Rotaro is covered with the arbutus, and other beautiful evergreens. Such is the strength of the virgin soil, that the shrubs have become almost arborescent; and the growth of some of the smaller wild plants has been so vigorous, that botanists have scarcely been able to recognise the species.

The eruption which dislodged the Syracusan colony is supposed to have given rise to that mighty current which forms the promontory of Zaro and Caruso. The surface of these lavas is still very arid and bristling, and is covered with black scoriæ; so that it is not without great labour that human industry has redeemed some small spots, and converted them into vineyards. Upon the produce of these vineyards the population of the island is almost entirely supported. It amounted when I was first there, in 1828, to about twenty-five thousand, and was on the increase.

From the date of the great eruption last alluded to, down to our own time, Ischia has enjoyed tranquillity, with the

Fig. 67.

Part of Ischia seen from the West. From a drawing by G. P. Scrope.

a. Monte Epomeo. *b.* Monte Vico.
c. Another of the minor cones with a crater.*

exception of one emission of lava hereafter to be described, which, although it occasioned much local damage, does not appear to have devastated the whole country, in the manner of more ancient explosions. There are, upon the whole, on different parts of Epomeo, or scattered through the lower tracts of Ischia, twelve considerable volcanic cones which have been thrown up since the island was raised above the surface of the deep; and many streams of lava may have flowed, like that of 'Arso' in 1302, without cones having been produced; so that this island may, for ages before the period of the remotest traditions, have served as a safety-valve to the whole Terra di Lavoro, while the fires of Vesuvius were dormant.

* See G. Poulett Scrope, Geol. Trans. 2d series, vol. ii. pl. 34.

Lake Avernus.—It seems also clear that Avernus, a circular lake near Puzzuoli, about half a mile in diameter, which is now a salubrious and cheerful spot, once exhaled mephitic vapours, such as are often emitted by craters after eruptions. There is no reason for discrediting the account of Lucretius, that birds could not fly over it without being stifled, although they may now frequent it uninjured.* There must have been a time when this crater was in action; and for many centuries afterwards it may have deserved the appellation of 'atri janua Ditis,' emitting, perhaps, gases as destructive of animal life as those suffocating vapours given out by Lake Quilotoa, in Quito, 1797, by which whole herds of cattle on its shores were killed,† or as those deleterious emanations which annihilated all the cattle in the island of Lancerote, one of the Canaries, in 1730.‡ Bory St. Vincent mentions, that in the same isle birds fell lifeless to the ground; and Sir William Hamilton informs us that he picked up dead birds on Vesuvius during an eruption.

Solfatara.—The Solfatara, near Puzzuoli, which may be considered as a nearly extinguished crater, appears, by the accounts of Strabo and others, to have been before the Christian era in very much the same state as at present, giving vent continually to aqueous vapour, together with sulphureous and muriatic acid gases, like those evolved by Vesuvius.

Ancient history of Vesuvius.—Such, then, were the points where the subterranean fires obtained vent, from the earliest period to which tradition reaches back, down to the first century of the Christian era; but we then arrive at a crisis in the volcanic action of this district—one of the most interesting events witnessed by man during the brief period throughout which he has observed the physical changes on the earth's surface. From the first colonisation of Southern Italy by the Greeks, Vesuvius afforded no other indications of its volcanic character than such as the naturalist might infer, from the analogy of its structure to other volcanos. These were recog-

* De Rerum Nat. vi. 740.—Forbes, on Bay of Naples, Edin. Journ. of Sci., No. iii. new series, p. 87. Jan. 1830.

† Humboldt, Voy., p. 317.

‡ Von Buch, Ueber einen vulcanischen Ausbruch auf der Insel Lanzerote.

nised by Strabo, but Pliny did not include this mountain in his list of active vents. The ancient cone was of a very regular form, terminating not as at present, in two peaks, but with a summit which presented, when seen from a distance, the ordinary outline of an abruptly truncated cone. On the summit, as we learn from Plutarch, there was a crater with steep cliffs, and having its interior overgrown with wild vines, and with a sterile plain at the bottom. On the exterior, the flanks of the mountains were clothed with fertile fields richly cultivated, and at its base were the populous cities of Herculaneum and Pompeii. But the scene of repose was at length doomed to cease, and the volcanic fire was recalled to the main channel, which at some former unknown period had given passage to repeated streams of melted lava, sand, and scoriæ.

Renewal of its eruptions.—The first symptom of the revival of the energies of this volcano was the occurrence of an earthquake in the year 63 after Christ, which did considerable injury to the cities in its vicinity. From that time to the year 79 slight shocks were frequent; and in the month of August of that year they became more numerous and violent, till they ended at length in an eruption. The elder Pliny, who commanded the Roman fleet, was then stationed at Misenum; and in his anxiety to obtain a near view of the phenomena, he lost his life, being suffocated by sulphureous vapours. His nephew, the younger Pliny, remained at Misenum, and has given us, in his Letters, a lively description of the awful scene. A dense column of vapour was first seen rising vertically from Vesuvius, and then spreading itself out laterally, so that its upper portion resembled the head, and its lower the trunk of the pine, which characterises the Italian landscape. This black cloud was pierced occasionally by flashes of fire as vivid as lightning, succeeded by darkness more profound than night. Ashes fell even upon the ships at Misenum, and caused a shoal in one part of the sea—the ground rocked, and the sea receded from the shores, so that many marine animals were seen on the dry sand. The appearances above described agree perfectly with those

witnessed in more recent eruptions, especially those of Monte Nuovo in 1538, and of Vesuvius in 1822.

The younger Pliny, although giving a circumstantial detail of so many physical facts, and describing the eruption and earthquake, and the shower of ashes which fell at Stabiæ, makes no allusion to the sudden overwhelming of two large and populous cities, Herculaneum and Pompeii. In explanation of this omission, it has been suggested that his chief object was simply to give Tacitus a full account of the particulars of his uncle's death. It is worthy, however, of remark, that had the buried cities never been discovered, the accounts transmitted to us of their tragical end might well have been discredited by the majority, so vague and general are the narratives, or so long subsequent to the event. Tacitus, the friend and contemporary of Pliny, when adverting in general terms to the convulsions, says merely that 'cities were consumed or buried.' *

Suetonius, although he alludes to the eruption incidentally, is silent as to the cities. They are mentioned by Martial, in an epigram, as immersed in cinders; but the first historian who alludes to them by name is Dion Cassius,† who flourished about a century and a half after Pliny. He appears to have derived his information from the traditions of the inhabitants, and to have recorded, without discrimination, all the facts and fables which he could collect. He tells us, 'that during the eruption a multitude of men of superhuman stature, resembling giants, appeared, sometimes on the mountain, and sometimes in the environs—that stones and smoke were thrown out, the sun was hidden, and then the giants seemed to rise again, while the sounds of trumpets were heard, &c. &c.; and finally,' he relates, 'two entire cities, Herculaneum and Pompeii, were buried under showers of ashes, while all the people were sitting in the theatre.' That many of these circumstances were invented, would have been obvious, even without the aid of Pliny's letters; and the examination of Herculaneum and Pompeii enables us to prove, that none of the people were destroyed in the theatres, and indeed, that there were very few of the inhabitants who

* 'Haustæ aut obrutæ urbes.'—Hist. lib. i.

† Hist. Rom. lib. lxvi.

did not escape from both cities. Yet some lives were lost, and there was ample foundation for the tale in its most essential particulars.

It does not appear that in the year 79 any lava flowed from Vesuvius; the ejected substances, perhaps, consisted entirely of lapilli, sand, and fragments of older lava, as when Monte Nuovo was thrown up in 1538. The first era at which we have authentic accounts of the flowing of a stream of lava, is the year 1036, which is the seventh eruption from the revival of the fires of the volcano. A few years afterwards, in 1049, another eruption is mentioned, and another in 1138 (or 1139), after which a great pause ensued of 168 years. During this long interval of repose, two minor vents opened at distant points. First, it is on tradition that an eruption took place from the Solfatara in the year 1198, during the reign of Frederick II., Emperor of Germany; and although no circumstantial detail of the event has reached us from those dark ages, we may receive the fact without hesitation.* Nothing more, however, can be attributed to this eruption, as Mr. Scrope observes, than the discharge of a light and scoriform trachytic lava (that of Monte Olivano), of recent aspect, resting upon the strata of loose tuff which cover the principal mass of trachyte.†

Volcanic eruption in Ischia, 1302.—The other occurrence is well authenticated,—the eruption, in the year 1302, of a lava-stream from a new vent on the south-east end of the Island of Ischia. During part of 1301, earthquakes had succeeded one another with fearful rapidity; and they terminated at last with the discharge of a lava-stream from a point named the Campo del Arso, not far from the town of Ischia. The lava ran quite down to the sea—a distance of about two miles: in colour it varies from iron grey to reddish black, and is remarkable for the glassy felspar which it contains. Its surface is almost as sterile, after a period of five centuries, as if it had cooled down yesterday. A few scantlings of wild thyme, and two or three other dwarfish

* The earliest authority, says Mr. Forbes, given for this fact, appears to be Capaccio, quoted in the Terra Tremante of Bonito.—Edin. Journ. of Sci. &c., No. i., new series, p. 127. July, 1829.

† Geol. Trans., second series vol. ii. p. 346.

plants, alone appear in the interstices of the scoriæ, while the Vesuvian lava of 1767 is already covered with a luxuriant vegetation. Pontanus, whose country-house was burnt and overwhelmed, describes the dreadful scene as having lasted two months.* Many houses were swallowed up, and a partial emigration of the inhabitants followed. This eruption produced no cone, but only a slight depression, hardly deserving the name of a crater, where heaps of black and red scoriæ lie scattered around. Until this eruption, Ischia is generally believed to have enjoyed an interval of rest for about seventeen centuries; but Julius Obsequens,† who flourished A.D. 214, refers to some volcanic convulsions in the year 662 after the building of Rome (91 B.C.). As Pliny, who lived a century before Obsequens, does not enumerate this among other volcanic eruptions, the story has been thought erroneous, and it may perhaps relate to some subterranean commotions of no great violence.

History of Vesuvius after 1138.—To return to Vesuvius:—the next eruption occurred in 1306; between which era and 1631 there was only one other (in 1500), and that a slight one. It has been remarked, that throughout this period Etna was in a state of such unusual activity, as to lend countenance to the idea that the great Sicilian volcano may sometimes serve as a channel of discharge to elastic fluids and lava that would otherwise rise to the vents in Campania. But we have not sufficient data as yet to enable us to form an opinion whether such a coincidence may not have been accidental and exceptional. When volcanic vents are distinctly arranged in a linear series, the subterranean connection of different portions of the line may be speculated upon more freely.

Formation of Monte Nuovo, 1538.—The great pause was also marked by a memorable event in the Phlegræan Fields—the sudden formation of a new mountain in 1538, of which we have received authentic accounts from contemporary writers.

The height of this mountain, called ever since Monte

* Lib. vi. de Bello Neap. in Grævii Thesaur.

† Prodig. libel. c. cxiv.

Nuovo, has been determined, by the Italian mineralogist Pini, to be 440 English feet above the level of the bay; its base is about 8,000 feet, or more than a mile and a half in circumference. According to Pini, the depth of the crater is 421 English feet from the summit of the hill, so that its bottom is only nineteen feet above the level of the sea. The cone is declared, by the best authorities, to stand partly on the site of the Lucrine Lake (4, fig. 69), which was nothing more than the crater of a pre-existent volcano,

Fig. 68.

Monte Nuovo, formed in the Bay of Baiæ, Sept. 29th, 1538.

1. Cone of Monte Nuovo. 2. Brim of crater of ditto.
3. Thermal spring, called Baths of Nero, or Stufe di Tritoli.

and was almost entirely filled during the explosion of 1538. Nothing now remains but a shallow pool, separated from the sea by an elevated beach, raised artificially.

Sir William Hamilton has given us two original letters describing this eruption. The first, by Falconi, dated 1538, contains the following passages.* 'It is now two years since there have been frequent earthquakes at Puzzuoli, Naples, and the neighbouring parts. On the day and in the night before the eruption (of Monte Nuovo), about twenty shocks, great and small, were felt. The eruption began on the 29th

* Campi Phlegræi, p. 70.

of September, 1538. It was on a Sunday, about one o'clock in the night, when flames of fire were seen between the hot baths and Tripergola. In a short time the fire increased to such a degree, that it burst open the earth in this place, and threw up so great a quantity of ashes and pumice-stones, mixed with water, as covered the whole country. The next morning (after the formation of Monte Nuovo) the poor inhabitants of Puzzuoli quitted their habitations in terror, covered with the muddy and black shower which continued the whole day in that country—flying from death, but with

Fig. 69.

The Phlegræan Fields.*

1. Monte Nuovo.
2. Monte Barbaro.
3. Lake Avernus.
4. Lucrine Lake.
5. The Solfatara.
6. Puzzuoli.
7. Bay of Baiæ.

death painted in their countenances. Some with their children in their arms, some with sacks full of their goods; others leading an ass, loaded with their frightened family, towards Naples; others carrying quantities of birds, of various sorts, that had fallen dead at the beginning of the eruption; others, again, with fish which they had found, and which were to be met with in plenty on the shore, the sea having left

* These representations of the Phlegræan Fields, figs. 68, and 69, are reduced from views given by Sir William Hamilton in his great work 'Campi Phlegræi.' The faithfulness of his coloured delineations of the scenery of that country cannot be too highly praised.

them dry for a considerable time. I accompanied Signor Moramaldo to behold the wonderful effects of the eruption. The sea had retired on the side of Baiæ, abandoning a considerable tract, and the shore appeared almost entirely dry, from the quantity of ashes and broken pumice-stones thrown up by the eruption. I saw two springs in the newly discovered ruins; one before the house that was the Queen's, of hot and salt water,' &c.

So far Falconi: the other account is by Pietro Giacomo di Toledo, which begins thus:—'It is now two years since this province of Campagna has been afflicted with earthquakes, the country about Puzzuoli much more so than any other parts: but on the 27th and the 28th of the month of September last, the earthquakes did not cease day or night in the town of Puzzuoli: that plain which lies between Lake Avernus, the Monte Barbaro, and the sea, was *raised a little*, and many cracks were made in it, from some of which issued water; at the same time the sea, immediately adjoining the plain, *dried up about two hundred paces*, so that the fish were left on the sand a prey to the inhabitants of Puzzuoli. At last on the 29th of the same month, about two o'clock in the night, the earth opened near the lake, and discovered a horrid mouth, from which were vomited furiously smoke, fire, stones, and mud, composed of ashes, making at the time of its opening a noise like the loudest thunder. The stones which followed were by the flames converted to pumice, and some of these were *larger than an ox*. The stones went about as high as a cross-bow can carry, and then fell down, sometimes on the edge, and sometimes into the mouth itself. The mud was of the colour of ashes, and at first very liquid, then by degrees less so, and in such quantities, that in less than twelve hours, with the help of the above-mentioned stones, a mountain was raised of 1,000 paces in height. Not only Puzzuoli and the neighbouring country was full of this mud, but the city of Naples also; so that many of its palaces were defaced by it. Now this eruption lasted two nights and two days without intermission, though, it is true, not always with the same force; the third day the eruption ceased, and I went up with many people to the top of the new hill, and saw

down into its mouth, which was a round cavity about a quarter of a mile in circumference, in the middle of which, the stones which had fallen were boiling up, just as a caldron of water boils on the fire. The fourth day it began to throw up again, and the seventh much more, but still with less violence than the first night. At this time many persons who were on the hill were knocked down by the stones and killed, or smothered with the smoke. In the day the smoke still continues, and you often see fire in the midst of it in the night-time.' *

It will be seen that both these accounts, written immediately after the birth of Monte Nuovo, agree in stating that the sea retired; and one mentions that its bottom was upraised; but they attribute the origin of the new hill exclusively to the jets of mud, showers of scoriæ, and large fragments of rock, cast out from a central orifice, for several days and nights. Baron Von Buch, however, in his excellent work on the Canary Islands, and volcanic phenomena in general, has declared his opinion that the cone and crater of Monte Nuovo were formed, not in the manner above described, but by the upheaval of solid beds of white tuff, which were previously horizontal, and were pushed up in 1538, so as to dip away in all directions from the centre, with the same inclination as the sloping surface of the cone itself. 'It is an error,' he says, 'to imagine that this hill was formed by eruption, or by the ejection of pumice, scoriæ, and other incoherent matter; for the solid beds of upraised tuff are visible all round the crater, and it is merely the superficial covering of the cone which is made up of ejected scoriæ.' †

In confirmation of this view, M. Dufrénoy has cited a passage from the works of Porzio, a celebrated physician of that period, to prove that in 1538 the ground where Monte Nuovo stands was pushed up in the form of a great bubble or blister, which on bursting gave origin to the present deep crater. Porzio says, 'that after two days and nights of violent earthquakes, the sea retired for nearly 200 yards; so that the inhabitants could collect great numbers of fish on

* Campi Phlegræi, p. 77. † P. 347. Paris, 1836.

this part of the shore, and see some springs of fresh water which rose up there. At length, on the third day of the calends of October (September 29), they saw a large tract of ground intervening between the foot of Monte Barbaro and part of the sea, near the Lake Avernus, rise, and suddenly assume the form of an incipient hill; and at two o'clock at night, this heap of earth, opening as it were its mouth, vomited, with a loud noise, flames, pumice-stones, and ashes.' *

So late as the year 1846 a fourth manuscript (written immediately after the eruption) was discovered and published in Germany. It was written in 1538 by Francesco del Nero,† who mentions the drying up of the bed of the sea near Puzzuoli, which enabled the inhabitants of the town to carry off loads of fish. At about eight o'clock in the morning of the 29th September, the earth sank down about fourteen feet in that place where the volcanic orifice now appears, and there issued forth a small stream of water, at first cold, and afterwards tepid. At noon, on the same day, the earth began to swell up in the same spot where it had sunk down fourteen feet, so as to form a hill. About this time fire issued forth, and gave rise to the great gulf, 'with such a force, noise, and shining light, that I, who was standing in my garden, was seized with terror. Forty minutes afterwards, although unwell, I got upon a neighbouring height, from which I saw all that took place, and by my troth it was a splendid fire, that threw up for a long time much earth and many stones, which fell back again all round the gulf, in a semicircle of from one to three bow-shots in diameter, and, filling up part of the sea, formed a hill nearly of the height of Monte Morello. Masses of earth and stones, as large as an ox, were shot up from the fiery gulf into the air, to a height which I

* 'Magnus terræ tractus, qui inter radices montis, quem Barbarum incolæ appellant, et mare juxta Avernum jacet, sese erigere videbatur, et montis subitò nascentis figuram imitari. Eo ipso die horâ noctis II., iste terræ cumulus, aperto veluti ore, magno cum fremitu, magnos ignes evomuit; pumicesque, et lapides, cineresque.' — Porzio, Opera Omnia, Medica, Phil., et Mathemat., in unum collecta, 1736, cited by Dufrénoy, Mém. pour servir à une Description Géologique de la France, tom. iv. p. 274.

† See Neues Jahr Buch for 1846, and a translation in the Quarterly Journ. of the Geol. Soc. for 1847, vol. iii. p. 20 Memoirs.

estimate at a mile and a half. When they descended, some were dry, others in a soft muddy state.' He concludes by alluding again to the sinking of the ground, and the elevation of it which followed, and says that to him it was inconceivable how such a mass of stones and ashes could have been poured forth from the gulf. He also refers to the account which Porzio was to draw up for the Viceroy.

On comparing these four accounts, recorded by eye-witnesses, there appears to be no real discrepancy between them. It seems clear that the ground first sank down fourteen feet on the site of the future volcano, and after having subsided it was again propelled upwards by the lava mingled with steam and gases, which were about to burst forth. Jets of red-hot lava, fragments of fractured rock, and occasionally mud composed of a mixture of pumice, tuff, and sea-water, were hurled into the air. Some of the blocks of stone were very large, leading us to infer that the ground which sank and rose again was much shattered and torn to pieces by the elastic vapours. The whole hill was not formed at once, but by an intermitting action extending over a week or more. It seems that the chasm opened between the Tripergola and the baths in its suburbs, and that the ejected materials fell and buried that small town. A considerable part, however, of the hill was formed in less than twenty-four hours, and in the same manner as on a smaller scale the mud cones of air volcanos are produced, with a cavity in the middle. There is no difficulty in conceiving that the pumiceous mud, if so thrown out, may have set into a kind of stone on drying, just as some cements, composed of volcanic ashes, are known to consolidate with facility.

I am informed that Baron Von Buch discovered some marine shells of existing species, such as occur fossil in the tuff of the neighbourhood, in beds exposed low down in the wall of the crater of Monte Nuovo. These may have been ejected in the mud mixed with sea-water which was cast out of the boiling gulf; or, as Signor Arcangelo Scacchi has suggested,* they may have been derived from the older tuff, which contains marine shells of recent species. The same

* Mem. Roy. Acad. Nap. 1849.

observer remarks that Porzio's account upon the whole corroborates the doctrine of the cone having being formed by eruption, in proof of which he cites the following passage:—'But what was truly astonishing, a hill of pumice-stones and ashes was heaped up round the gulf, to the height of a mile in a single night.'* Signor Scacchi also adds that the ancient temple of Apollo, now at the foot of Monte Nuovo, and the walls of which still retain their perfect perpendicularity, could not possibly have maintained that position had the cone of Monte Nuovo really been the result of upheaval.

Tripergola was much frequented as a watering-place, and contained an hospital for those who resorted there for the benefit of the thermal springs; and it appears that there were no fewer than three inns in the principal street. Had Porzio stated that any of these buildings, or the ruins of them, were seen by himself and others raised up above the plain, a short time before the first eruption, so as to stand on the summit or slope of a newly-raised hillock, we might have been compelled, by so circumstantial a narrative, to adopt M. Dufrénoy's interpretation.

But in the absence of such evidence, we must appeal to the crater itself, where we behold a section of the whole mountain, without being able to detect any original nucleus of upheaved rock distinct from the rest: on the contrary, the whole mass is similar throughout in composition, and the cone very symmetrical in form; nor are there any clefts, such as might be looked for, as the effect of the sudden upthrow of stony masses. Mr. C. Prévost has well remarked that if beds of solid and non-elastic materials had yielded to a violent pressure directed from below upwards, we should find not simply a deep empty cavity, but an irregular opening, where many rents converged; and these rents would be now seen breaking through the walls of the crater, widening as they approach the centre. (See fig. 70, *a*, *b*.)† Not a single fissure of this kind is observable in the interior of Monte Nuovo, where the walls of the crater are continuous and

* 'Verum quod omnem superat admirationem, mons circum eam voraginem ex pummicibus et cinere plusquàm mille passuum altitudine unâ nocte congestus aspicitur.'

† Mém. de la Soc. Géol. de France, tom. ii. p. 91.

entire; nor are there any dikes implying that rents had existed which were afterwards filled with lava or other matter.

It has moreover been often urged by Von Buch, De Beaumont, and others, who ascribe the conical form of volcanos chiefly to upheaval from below, that in such mountains there are a great number of deep rents and ravines, which diverge on all sides like the spokes of a wheel, from near the central axis to the circumference or base of the cone, as in the case of Palma, Cantal, and Teneriffe. Yet the entire absence of such divergent fissures or ravines, in such cases as Monte Nuovo, Somma, or Etna, is passed by unnoticed, and appears to have raised in their minds no objection to their favourite theory.

Fig. 70.

It is, indeed, admitted by M. Dufrénoy that there are some facts which it is very difficult to reconcile with his own view of Porzio's record. Thus, for example, there are certain Roman monuments at the base of Monte Nuovo, and on the borders of Lake Avernus, such as the temples of Apollo (before mentioned) and Pluto, which do not seem to have suffered in the least degree by the supposed upheaval. 'The walls which still exist have preserved their vertical position, and the vaults are in the same state as other monuments on the shores of the Bay of Baiæ. The long gallery which led to the Sibyl's Cave, on the other side of Lake Avernus, has in like manner escaped injury, the roof of the gallery remaining perfectly horizontal, the only change being that the soil of the chamber in which the Sibyl gave out her oracles is now covered by a few inches of water, which merely indicates a slight alteration in the level of Lake Avernus.'* On the supposition, then, that pre-existing beds of pumiceous tuff were upraised in 1538, so as to form Monte Nuovo, it is acknowledged that the perfectly undisturbed state of the contiguous soil on which these ancient monuments stand, is very different from what might have been expected.

* Dufrénoy, Mém. pour servir, &c., p. 277.

Mr. Darwin, in his 'Volcanic Islands,' has described several crateriform hills in the Galapagos Archipelago as composed of tuff which has evidently flowed like mud, and yet on consolidating has preserved an inclination of twenty and even thirty degrees. The tuff does not fold in continuous sheets round the hills as would have happened if they had been formed by the upheaval of horizontal layers. The author describes the composition of the tuff as very similar to that of Monte Nuovo, and the high angles at which the beds slope, both those which have flowed and those which have fallen in the form of ashes, entirely removes the difficulty supposed by M. Dufrénoy to exist in regard to the slope of Monte Nuovo, where it exceeds an angle of 18° to 20°.* Mr. Dana, also, in his account of the Sandwich Islands,† shows that in the 'cinder cones' of that region, the strata have an original inclination of between 35° and 40°, while in the 'tufa cones' formed near the sea, the beds slope at about an angle of 30°. The same naturalist also observed in the Samoan or Navigator Islands in Polynesia, that fragments of fresh coral had been thrown up together with volcanic matter to the height of 200 feet above the level of the sea in cones of tufa.‡

In October, 1857, I re-examined Monte Nuovo in company with Prof. A. Scacchi. On the south side of the mountain I saw both large and small blocks of trachyte entering into its composition, together with scoriæ, just as we might have expected from the accounts handed down to us of the eruption. In the interior of the crater on the east and north-east side an internal talus is seen, the beds of which slope at angles of 26° and 30° towards the centre or axis of the cone as at *a*, fig. 71. Such taluses are well known as characterising cones of eruption, being formed by those ejected materials which fall inside the margin of the wall of the crater, and which, although for the most part ejected again during subsequent explosions, often leave some monuments of their former existence. We found several fragments of marine

* Darwin's Volcanic Islands, p. 106, note.

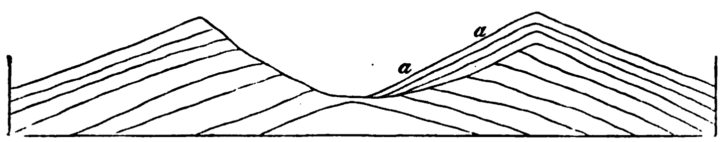
† Geology of the American Exploring Expedition, in 1838—1842, p. 354.

‡ Ibid. p. 328.

shells *Cardium*, *Cerithium*, &c., as well as of Roman bricks, in these strata, and I myself picked up three pieces of pottery. Such remains are just what we might have looked for; they are such as would have been showered down from above on a spot where the gaseous explosions burst through marine accumulations like those of the Starza, and by which the houses of Tripergola were blown into the air.

I shall again revert to the doctrine of the origin of volcanic cones by upheaval, when speaking of Vesuvius, Etna, and Santorin, and shall now merely add, that, in 1538, the whole coast, from Monte Nuovo to beyond Puzzuoli, was upraised to the height of many feet above the bed of the Mediterranean, and has since retained the greater part of the elevation then acquired. The proofs of these remarkable changes of level will be considered at length when the phenomena of the temple of Serapis are described.*

Fig. 71.



Section of Monte Nuovo showing the internal talus, *a*, *a*, on the inner slope of the crater on its north-east side.

Volcanos of the Phlegræan Fields.—Immediately adjoining Monte Nuovo is the larger volcanic cone of Monte Barbaro (2, fig. 69, p. 609), the 'Gaurus inanis' of Juvenal—an appellation given to it probably from its deep circular crater, which is about a mile in diameter. Large as is this cone, it was probably produced by a single eruption; and it does not, perhaps, exceed in magnitude some of the largest of those formed in Ischia, within the historical era. It is composed chiefly of indurated tufa like Monte Nuovo, stratified conformably to its conical surface. This hill was once very celebrated for its wines, and is still covered with vineyards; but when the vine is not in leaf it has a sterile appearance, and, late in the year, when seen from the beautiful Bay of Baiæ,

* See Chap. XXIX.

it often contrasts so strongly in verdure with Monte Nuovo, which is always clothed with arbutus, myrtle, and other wild evergreens, that a stranger might well imagine the cone of older date to be that thrown up in the sixteenth century.*

There is nothing, indeed, so calculated to instruct the geólogist as the striking manner in which the recent volcanic hills of Ischia, and that now under consideration, blend with the surrounding landscape. Nothing seems wanting or redundant; every part of the picture is in such perfect harmony with the rest, that the whole has the appearance of having been called into existence by a single effort of creative power. Yet what other result could we have anticipated if Nature has ever been governed by the same laws? Each new mountain thrown up—each new tract of land raised or depressed by earthquakes—should be in perfect accordance with those previously formed, if the entire configuration of the surface has been due to a long series of similar disturbances. Were it true that the greater part of the dry land originated simultaneously in its present state, at some era of paroxysmal convulsion, and that additions were afterwards made slowly and successively during a period of comparative repose; then, indeed, there might be reason to expect a strong line of demarcation between the signs of the ancient and modern changes. But the very continuity of the plan, and the perfect identity of the causes, are to many a source of deception; since by producing a unity of effect, they lead them to exaggerate the energy of the agents which operated in the earlier ages. In the absence of all historical information, they are as unable to separate the dates of the origin of different portions of our continents, as the stranger is to determine, by their physical features alone, the distinct ages of Monte Nuovo, Monte Barbaro, Astroni, and the Solfatara.

The vast scale and violence of the volcanic operations in Campania, in the olden time, has been a theme of declamation, and has been contrasted with the comparative state

* Hamilton (writing in 1770) says, 'the new mountain produces as yet but a very slender vegetation.'—Campi Phlegræi, p. 69. This remark was no longer applicable when I saw it, in 1828.

of quiescence of this delightful region in the modern era. Instead of inferring, from analogy, that the ancient Vesuvius was always at rest when the craters of the Phlegræan Fields were burning—that each cone rose in succession,—and that many years, and often centuries, of repose intervened between different eruptions,—geologists seem to have generally conjectured that the whole group sprang up from the ground at once, like the soldiers of Cadmus when he sowed the dragon's teeth. As well might they endeavour to persuade us that on these Phlegræan Fields, as the poets feigned, the giants warred with Jove, ere yet the puny race of mortals were in being.

Modern eruptions of Vesuvius.—For nearly a century after the birth of Monte Nuovo, Vesuvius continued in a state of tranquillity. There had then been no violent eruption for 492 years; and it appears that the crater was then exactly in the condition of the present extinct volcano of Astroni, near Naples. Bracini, who visited Vesuvius not long before the eruption of 1631, gives the following interesting description of the interior:—'The crater was five miles in circumference, and about a thousand paces deep: its sides were covered with brushwood, and at the bottom there was a plain on which cattle grazed. In the woody parts wild boars frequently harboured. In one part of the plain, covered with ashes, were three small pools, one filled with hot and bitter water, another salter than the sea, and a third hot, but tasteless.'* But at length these forests and grassy plains were consumed, being suddenly blown into the air, and their ashes scattered to the winds. In December, 1631, seven streams of lava poured at once from the crater, and overflowed several villages on the flanks and at the foot of the mountain. Resina, partly built over the ancient site of Herculaneum, was consumed by the fiery torrent. Great floods of mud were as destructive as the lava itself,—no uncommon occurrence during these catastrophes; for such is the violence of rains produced by the evolutions of aqueous vapour, that torrents of water descend the cone, and becoming charged

* Hamilton's Campi Phlegræi, folio, vol. i. p. 62; and Brieslak, Campania, tome i. p. 186.

with impalpable volcanic dust, and rolling along loose ashes, acquire sufficient consistency to deserve their ordinary appellation of 'aqueous lavas.'

A brief period of repose ensued, which lasted only until the year 1666, from which time to the present there has been a constant series of eruptions, with rarely an interval of rest exceeding ten years. During these three centuries, no irregular volcanic agency has convulsed other points in this district. Brieslak remarked, that such irregular convulsions had occurred in the Bay of Naples in every second century; as, for example, the eruption of the Solfatara in the twelth; of the lava of Arso, in Ischia, in the fourteenth; and of Monte Nuovo in the sixteenth: but the eighteenth has formed an exception to this rule, and this seems accounted for by the unprecedented number of eruptions of Vesuvius during that period; whereas, when the new vents opened, there had always been, as we have seen, a long intermittence of activity in the principal volcano.

CHAPTER XXV.

VOLCANIC DISTRICT OF NAPLES—*continued.*

DIMENSIONS AND STRUCTURE OF THE CONE OF VESUVIUS—FLUIDITY AND MOTION OF LAVA—ROPY SCORIÆ—DIKES—HYPOTHESIS OF ELEVATION CRATERS NOT APPLICABLE TO SOMMA AND VESUVIUS—SECTIONS SEEN IN VALLEYS ON THE NORTH SIDE OF MONTE SOMMA—ALLUVIUMS CALLED 'AQUEOUS LAVAS'—ORIGIN AND COMPOSITION OF THE MATTER ENVELOPING HERCULANEUM AND POMPEII—CONDITION AND CONTENTS OF THE BURIED CITIES—SMALL NUMBER OF SKELETONS—STATE OF PRESERVATION OF ANIMAL AND VEGETABLE SUBSTANCES—ROLLS OF PAPYRUS—STABIÆ—TORRE DEL GRECO—CONCLUDING REMARKS ON THE CAMPANIAN VOLCANOS.

Structure of the cone of Vesuvius.—BETWEEN the end of the eighteenth century and the year 1822, the great crater of Vesuvius had been gradually filled by lava boiling up from below, and by scoriæ falling from the explosions of minor mouths which were formed at intervals on its bottom and sides. In place of a regular cavity, therefore, there was a rough and rocky plain, covered with blocks of lava and scoriæ, and cut by numerous fissures, from which clouds of vapour were evolved. But this state of things was totally changed by the eruption of October 1822, when violent explosions, during the space of more than twenty days, broke up and threw out all this accumulated mass, so as to leave an immense gulf or chasm, of an irregular, but somewhat elliptical shape, about three miles in circumference when measured along the very sinuous and irregular line of its extreme margin, but somewhat less than three quarters of a mile in its longest diameter, which was directed from N.E. to S.W.* The depth of this tremendous abyss has been variously estimated; for from the hour of its formation it

* Account of the Eruption of Vesuvius in October 1822, by G. P. Scrope, Esq., Journ. of Sci. &c. vol. xv. p. 175.

diminished daily by the dilapidation and falling in of its sides. It measured, at first, according to the account of some authors, 2,000 feet in depth from the extreme part of the existing summit;* but Mr. Scrope, when he saw it, soon after the eruption, estimated its depth at less than half that amount. More than 800 feet of the cone was carried away by the explosions, so that the mountain was reduced in height from about 4,200 to 3,400 feet.†

As we ascend the sloping sides, the volcano appears a mass of loose materials—a mere heap of rubbish, thrown together without the slightest order; but on arriving at the brim of the crater, and obtaining a view of the interior, we are agreeably surprised to discover that the conformation of the whole displays in every part the most perfect symmetry and arrangement. The materials are disposed in regular strata, slightly undulating, appearing, when viewed in front to be disposed in horizontal planes. But, as we make the circuit of the edge of the crater, and observe the cliffs by which it is encircled projecting or receding in salient or retiring angles, we behold transverse sections of the currents of lava and beds of sand and scoriæ, and recognise their true dip. We then discover that they incline outwards from the axis of the cone, at angles varying from 25° to 40°. The whole cone, in fact, is composed of a number of concentric coatings of alternating lavas, sand, and scoriæ. Every shower of ashes which has fallen from above, and every stream of lava descending from the lips of the crater, have conformed to the outward surface of the hill, so that one conical envelope may be said to have been successively folded round another, until the aggregation of the whole mountain was completed. The marked separation into distinct beds results from the different colours and degrees of coarseness in the sands, scoriæ, and lava, and the alternation of these with each other. The greatest difficulty, on the first view, is to conceive how so much regularity can be produced, notwithstanding the unequal distribution of sand and scoriæ, driven by prevailing

* Mr. Forbes, Account of Mount Vesuvius, Edin. Journ. of Sci. No. xviii. p. 195. Oct. 1828.

† Ibid. p. 195.

winds in particular eruptions, and the small breadth of each sheet of lava as it first flows out from the crater.

But, on a closer examination, we find that the appearance of extreme uniformity is delusive; for when a number of beds thin out gradually, and at different points, the eye does not without difficulty recognise the termination of any one stratum, but usually supposes it continuous with some other, which at a short distance may lie precisely in the same plane. The difficulty, moreover, of following any given layer is increased by its undulating form, produced by the moulding of successive layers on the outer sides of a cone, which can never preserve perfect symmetry owing to its irregular mode of growth. As countless beds of sand and scoriæ constitute the greater part of the whole mass, these may sometimes mantle continuously round the whole cone; and even lava-streams may be of considerable breadth when first they overflow, and since, in some eruptions, a considerable part of the upper portion of the cone breaks down at once, may form a sheet extending as far as the space which the eye usually takes in, in a single section.

The high inclination of some of the beds, and the firm union of the particles even where there is evidently no cement, is another striking feature in the volcanic tuffs and breccias, which seems at first not very easy of explanation. But the great eruption of 1822 afforded ample illustration of the manner in which these strata are formed. Fragments of lava, scoriæ, pumice, and sand, when they fall at slight distances from the summit, are only half cooled down from a state of fusion, and are afterwards acted upon by the heat from within, and by fumeroles or small crevices in the cone through which hot vapours are disengaged. Thus heated, the ejected fragments cohere together strongly; and the whole mass acquires such consistency in a few days, that fragments cannot be detached without a smart blow of the hammer. At the same time sand and scoriæ, ejected to a greater distance, remain incoherent.*

Sir William Hamilton, in his description of the eruption of 1779, says, that jets of liquid lava, mixed with stones and

* Monticelli and Covelli, Storia di Fenom. del. Vesuv. in 1821-23.

scoriæ, were thrown up to the height of at least 10,000 feet, having the appearance of a column of fire.* Some of these were directed by the winds towards Ottajano, and some of them, falling almost perpendicularly, still red-hot and liquid, on Vesuvius, covered its whole cone, part of the mountain of Somma, and the valley (the Atrio) between them. The falling matter being nearly as vividly inflamed as that which was continually issuing fresh from the crater, formed with it one complete body of fire, which could not be less than two miles and a half in breadth, and of the extraordinary height above mentioned, casting a heat to the distance of at least six miles round it. Dr. Clarke, also, in his account of the eruption of 1793, says that millions of red-hot stones were shot into the air full half the height of the cone itself, and then bending, fell all round in a fine arch. On another occasion he says that, as they fell, they covered nearly half the cone with fire.

The same author has also described the different appearance of the lava at its source, and at some distance from it, when it had descended into the plains below. At the point where it issued, in 1793, from an arched chasm in the side of the mountain, the vivid torrent rushed with the velocity of a flood. It was in perfect fusion, unattended with any scoriæ on its surface, or any gross materials not in a state of complete solution. It flowed with the translucency of honey, 'in regular channels, cut finer than art can imitate, and glowing with all the splendour of the sun.'—'Sir William Hamilton,' he continues, 'had conceived that no stones thrown upon a current of lava would make any impression. I was soon convinced of the contrary. Light bodies, indeed, of five, ten, and fifteen pounds' weight, made little or no impression even at the source; but bodies of sixty, seventy, and eighty pounds were seen to form a kind of bed on the surface of the lava, and float away with it. A stone of 300 cwt., that had been thrown out by the crater, lay near the source of the current of lava: I raised it upon one end, and then let it fall upon the liquid lava; when it gradually sank beneath the surface, and disappeared. If I wished to describe the manner

* Campi Phlegræi.

in which it acted upon the lava, I should say that it was like a loaf of bread thrown into a bowl of very thick honey, which gradually involves itself in the heavy liquid, and then slowly sinks to the bottom.

'The lava, at a small distance from its source, acquires a darker tint upon its surface, is less easily acted upon, and, as the stream widens, the surface, having lost its state of perfect solution, grows harder and harder, and cracks into innumerable fragments of very porous matter, to which they give the name of scoriæ, and the appearance of which has led many to suppose that it proceeded thus from the mountain. There is, however, no truth in this. All lava, at its first exit from its native volcano, flows out in a liquid state, and all equally in fusion. The appearance of the scoriæ is to be attributed only to the action of the external air, and not to any difference in the materials which compose it, since any lava whatever, separated from its channel, and exposed to the action of the external air, immediately cracks, becomes porous, and alters its form. As we proceeded downward, this became more and more evident; and the same lava which at its original source flowed in perfect solution, undivided, and free from incumbrances of any kind, a little farther down had its surface loaded with the scoriæ in such a manner, that, upon its arrival at the bottom of the mountain, the whole current resembled nothing so much as a heap of unconnected cinders from an iron-foundry.' In another place he says, that 'the rivers of lava in the plain resembled a vast heap of cinders, or the scoriæ of an iron-foundry, rolling slowly along, and falling with a rattling noise over one another.'* Von Buch, who was in company with MM. de Humboldt and Gay-Lussac, describes the lava of 1805 (the most fluid on record) as shooting suddenly before their eyes from top to bottom of the cone in one single instant. Professor J. D. Forbes remarks that the length of the slope of the cone proper being about 1,300 feet, this motion must correspond to a velocity of many hundred feet in a few seconds, without interpreting Von Buch's expression literally. The same lava, when it reached the level road at Torre del

* Otter's Life of Dr. Clarke.

Greco, moved at the rate of only eighteen inches per minute, or three tenths of an inch per second.* 'Although common lava,' observes Professor Forbes, 'is nearly as liquid as melted iron, when it issues from the orifice of the crater, its fluidity rapidly diminishes, and as it becomes more and more burdened by the consolidated slag through which it has to force its way, its velocity of motion diminishes in an almost inconceivable degree; and at length, when it ceases to present the slightest external trace of fluidity, its movement can only be ascertained by careful and repeated observations, just as in the case of a glacier.'†

It appears that the intensity of the light and heat of the lava varies considerably at different periods of the same eruption, as in that of Vesuvius in 1819 and 1820, when Sir H. Davy remarked different degrees of vividness in the white heat at the point where the lava originated.‡

When the expressions 'flame' and 'smoke' are used in describing volcanic appearances, they must generally be understood in a figurative sense. We are informed, indeed, by M. Abich, that he distinctly saw, in the eruption of Vesuvius in 1834, the flame of burning hydrogen §; but what is usually mistaken for flame consists of vapour or scoriæ, and impalpable dust illuminated by that vivid light which is emitted from the crater below, where the lava is said to glow with the splendour of the sun. The clouds of apparent smoke are formed either of aqueous and other vapour, or of finely comminuted scoriæ.

Ropy scoriæ.—In their descriptions of lava, geologists often speak of 'ropy scoriæ,' for sometimes a large portion of the scoriform surface assumes the appearance of coils of cable. This structure I saw very conspicuously displayed by the lava of 1857, where it had poured over from the lip of the crater and descended the N.N.E. side of the cone. There were no loose fragments of scoriæ upon it, and the surface had the form partly of ropes and partly of the roots of trees. Occasionally we may observe such lavas on Etna

* Phil. Trans. 1846, p. 154.

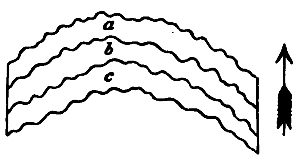
† Ibid. p. 148.

‡ Ibid. p. 241.

§ Bulletin de la Soc. Géol. de France, tom. vii. p. 43; and Illustration of Vesuvius and Etna, p. 3.

and Vesuvius, especially near the points from which they issued, exhibiting, for a short distance, flattened spaces a few feet or yards wide, on which the rope-like coils are arranged one within another, all bending the same way, as *a b c* in fig. 72. I had an opportunity in 1858 of seeing the manner

Fig. 72.



in which this structure originates. The highest crater of Vesuvius was then tranquil or only emitting steam; but half way down the mountain on the side towards Naples and below the Piano di Ginestra, were two cones which had recently been thrown up. Near the base of one of these was a grotto, from which lava had been flowing without intermission for several months, and was still pouring out in a perfectly liquid state. It had built up a ridge between 10 and 15 feet in height, at the top of which it had formed a straight canal 5 feet wide. At the point where it issued from the grotto, it seemed as fluid as water and was at a white heat. In order to enable me to approach near enough to watch its movements without being scorched, my guides held up between me and the fiery stream a bull's-hide screen pierced with small holes through which we looked.

At the distance of about two yards from the grotto, the lava flowing with great velocity in the canal, began to turn from white to red, and a few feet farther on it acquired a darker colour, and many small separate pieces of scoriæ were seen floating on its surface, showing that solidification had commenced. About four yards from the point of efflux, the surface of the stream had already become black, and the detached pieces of scoriæ had begun to be pressed against each other so as to unite, and they soon became welded together into continuous ropy coils, each set bending forward in the middle where the stream ran fastest, and fitting one within the other, as in fig. 72. Their successive formation and

arrangement reminded me of the manner in which wreaths of foam collect on a river below a cataract or the piers of a bridge, and being carried by a current or by the wind against a bank or island, retain for some time the marks of having been formed on the surface one after the other. The course of a lava-stream may always be known by the direction in which such coils are bent.

Dikes in the recent cone, how formed.—The inclined strata before mentioned which dip outwards in all directions from the axis of the cone of Vesuvius, are intersected by veins or dikes of compact lava, for the most part in a vertical position. In 1828, these were seen to be about seven in number, some of them not less than 400 or 500 feet in height, and thinning out before they reached the uppermost part of the cone. Being harder than the beds through which they pass, they have decomposed less rapidly, and therefore stand out in relief. When I visited Vesuvius, in November 1828, I was prevented from descending into the crater by the constant ejections then thrown out; so that I got sight of three only of the dikes; but Signor Monticelli had previously had drawings made of the whole, which he showed me. The dikes which I saw were on that side of the cone which is encircled by Somma. The eruption before mentioned, of 1828, began in March, and in the November following the ejected matter had filled up nearly one-third of the deep abyss formed at the close of the eruption in 1822. In November I found a single black cone at the bottom of the crater continually throwing out scoriæ, while on the exterior of the cone I observed the lava of 1822, which had flowed out six years before, not yet cool, and still evolving much heat and vapour from crevices.

Hoffmann, in 1832, saw on the north side of Vesuvius, near the peak called Palo, a great many parallel bands of lava, some from 6 to 8 feet thick, alternating with scoriæ and conglomerate. These beds, he says, were cut through by many dikes, some of them 5 feet broad. They resemble those of Somma, the stone being composed of grains of leucite and augite.*

* Geognost. Beobachtungen, &c. p. 182. Berlin, 1839.

There can be no doubt that the dikes above mentioned have been produced by the filling up of open fissures with liquid lava; but of the date of their formation we know nothing farther than that they are all subsequent to the year 79, and, relatively speaking, that they are more modern than all the lavas and scoriæ which they intersect. A considerable number of the upper strata are not traversed by them. That the earthquakes, which almost invariably precede eruptions, occasion rents in the mass, is well known; and, in 1822, three months before the lava flowed out, open fissures, evolving hot vapours, were numerous. It is clear that such rents must be injected with melted matter when the column of lava rises, so that the origin of the dikes is easily explained, as also the great solidity and crystalline nature of the rock composing them, which has been formed by lava cooling slowly under great pressure.

Scacchi, in his detailed narrative of what happened from day to day in the eruption of 1850, gives an account of a long linear opening or fracture on the N.N.E. side of the cone of Vesuvius, from one part of which lava issued. This chasm marked, no doubt, the site of what has now become a dike traversing the mountain. When Signor Scacchi accompanied me to the Atrio, in 1858, the chasm alluded to was still visible on the slope of the cone, though even then it had been partly filled by the lava of 1857, which descending from the lip of the crater had flowed into it.

It has been suggested that the frequent rending of volcanic cones during eruptions may be connected with the gradual and successive upheaval, of the whole mass in such a manner as to increase the inclination of the beds composing the cone; and in accordance with the hypothesis before proposed for the origin of Monte Nuovo, Von Buch supposes that the present cone of Vesuvius was formed in the year 79, not by eruption, but by upheaval; and that it was not produced by the repeated superposition of scoriæ and lava cast out or flowing from a central source, but by the uplifting of strata previously horizontal. The entire cone, according to his view, rose at once, such as we now see it, from the interior and middle of Somma, and has since received no accession of

height, but, on the contrary, has ever since been diminishing in elevation.*

I shall endeavour to show that this hypothesis of Von Buch, whether applied to the modern cone of Vesuvius or to the more ancient cone called Somma, is wholly untenable. But before enlarging on this topic, I may mention some facts recorded by M. Abich in his account of the Vesuvian eruptions of 1833 and 1834, because they might seem at first sight to favour the possibility of such a mode of origin.† In the year 1834, the great crater of Vesuvius had been filled up nearly to the top with lava, which had consolidated and formed a level and unbroken plain, except that one small cone of scoriæ had been thrown up, which rose in the middle of the plain like an island in a lake. At length this flat area of lava was broken by a fissure which passed from N.E. to S.W., and along this line a great number of minute cones emitting vapour were produced. The first act of formation of these minor cones consisted, according to Abich, of a partial upheaval of beds of lava previously horizontal, and which had been rendered flexible by the heat and tension of elastic fluids, which, rising from below, escaped from the centre of each new monticule. There would be considerable analogy between this mode of origin and that ascribed by Von Buch to Vesuvius and Somma, if the dimensions of the upraised masses were not on so different a scale, and if it was safe to reason from the inflation of bladders of half-fused lava, from 15 to 25 feet in height, to mountains attaining an altitude of several thousand feet, and having their component strata strengthened by intersecting dikes of solid lava.

At the same time M. Abich mentions, that when, in August 1834, a great subsidence took place in the platform of lava within the great crater, so that the structure of the central cone was laid open, it was seen to have been evidently formed, *not by upheaval*, but by the fall of cinders and scoriæ which had been thrown out during successive eruptions.‡

Mr. Scrope, writing in 1827, attributed the formation of a

* Von Buch, Descrip. Phys. des Iles Canaries, p. 342. Paris, 1836.

† Abich, Vues Illust. de Phénom. Géol. sur le Vésuve et l'Etna. Berlin, 1837.

‡ Ibid. p. 2.

volcanic cone chiefly to matter ejected from a central orifice, but partly to the injection of lava into dikes, and 'to that force of gaseous expansion, the intensity of which, in the central parts of the cone, is attested by local earthquakes, which so often accompany eruptions.' * The inclination of some of the lavas may, no doubt, have been modified in some cases during the rending and dislocation of the cone, but I do not believe, any more than does the author just cited, that such disturbances have played a conspicuous part in giving to volcanic mountains the configuration, whether external or internal, by which they are distinguished.

Previous to the year 79 of our era, Vesuvius appears, from the description of its figure given by Strabo, to have been a truncated cone, having a level and even outline as seen from a distance. That it had a crater on its summit, we may infer from a passage in Plutarch, on which Dr. Daubeny has judiciously commented in his treatise on volcanos.† The walls of the crater were evidently entire, except on one side, where there was a single narrow breach. When Spartacus, in the year 72 B.C., encamped his gladiators in this hollow, Clodius, the prætor, besieged him there, keeping the single outlet carefully guarded, and then let down his soldiers by scaling ladders over the steep precipices which surrounded the crater, at the bottom of which the insurgents were encamped. On the side towards the sea, the walls of this original cavity, which must have been three miles in diameter, have been destroyed, and Brieslak was the first to announce the opinion that this destruction happened during the tremendous eruption which occurred in A.D. 79, when the new cone, now called Vesuvius, was thrown up, which stands encircled on three sides by the ruins of the ancient cone, called Monte Somma.

In the annexed diagram (fig. 73) it will be seen that on the side of Vesuvius opposite to that where a portion of the ancient cone of Somma (*a*) still remains, is a projection (*b*) called the Pedamentina, which some have supposed to be part of the circumference of the ancient crater broken down towards the sea, and over the edge of which the lavas of the

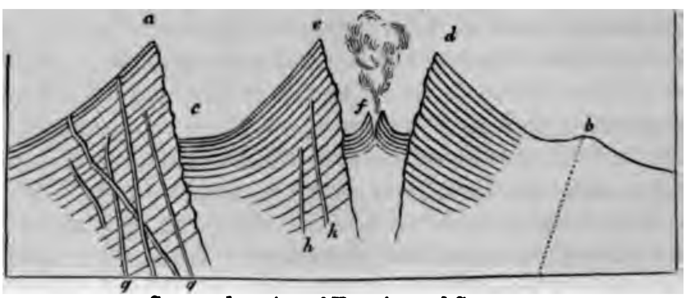
* Geol. Trans. 2nd series, vol. ii. p. 341.

† 2nd edit. 1848, p. 216.

modern Vesuvius have poured; the axis of the present cone of Vesuvius being, according to Visconti, precisely equidistant from the escarpment of Somma and the Pedamentina.

In the same diagram I have represented the slanting beds of the cone of Vesuvius as becoming horizontal in the Atrio del Cavallo at (c), where the base of the new cone meets the precipitous escarpment of Somma; for when the lava flows down to this point, as happened in 1822, its descending course is arrested, and it then runs in another direction along this

Fig. 72.



Supposed section of Vesuvius and Somma.

a. Monte Somma, or the remains of the ancient cone of Vesuvius.
b. The Pedamentina, a terrace-like projection, encircling the base of the recent cone of Vesuvius on the south side.
c. Atrio del Cavallo.*
d, *e*. Crater left by eruption of 1822.
f. Small cone thrown up in 1828, at the bottom of the great crater.
g, *g*. Dikes intersecting Somma.
h, *h*. Dikes intersecting the recent cone of Vesuvius.
N.B. The inclination of the beds at *a*, *e*, *f*, *d*, is considerably exaggerated in this diagram for want of more space.

small valley, circling round the base of the cone. Sand and scoriæ, also, blown by the winds, collect at the base of the cone, and are then swept away by torrents; so that there is always here a flattish plain, as represented. In the same manner, the small interior cone (*f*) must be composed of sloping beds, terminating in a horizontal plain; for, while this monticule was gradually gaining height by successive ejections of lava and scoriæ, in 1828, it was always sur-

* So called from travellers leaving their horses and mules there when they prepare to ascend the cone on foot.

rounded by a flat pool of semi-fluid lava, into which scoriæ and sand were thrown.

In the steep semicircular escarpment of Somma, which faces the modern Vesuvius, we see a great number of sheets of lava inclined at an angle of about 26° and in some rare cases of 30° and more. They alternate with scoriæ, and are intersected by numerous dikes from two to four feet thick, which, like the sheets of lava, are composed chiefly of augite, with crystals of leucite, but the rock in the dikes is more compact, having cooled and consolidated under greater pressure. I saw one dike two feet thick composed of leucite and augite in that part of the wall of the Atrio called Canale del Inferno, which was as vesicular as ordinary lava; but this case is quite exceptional. Some of the dikes cut through and shift others, so that they have evidently been formed during successive eruptions.

Vesuvian minerals.—A great variety of minerals are found in the lavas of Vesuvius and Somma; augite, leucite (called by the French amphigéne), felspar, mica, and olivine are most abundant. It is an extraordinary fact, that, in an area of three square miles round Vesuvius, a greater number of simple minerals have been found than in any spot of the same dimensions on the surface of the globe. Häuy enumerated only 380 species of simple minerals as known to him; and no less than eighty-two had been found on Vesuvius and in the tuffs on the flanks of Somma before the end of the year 1828. Many of these are peculiar to that locality. Some mineralogists have conjectured that the greater part of these were not of Vesuvian origin, but thrown up in fragments from some older formation, through which the gaseous explosions burst. But none of the older rocks in Italy, or elsewhere, contain such an assemblage of mineral products; and the hypothesis seems to have been prompted by a disinclination to admit that, in times so recent in the earth's history, the laboratory of Nature could have been so prolific in the creation of new and rare compounds. Had Vesuvius been a volcano of high antiquity, formed when nature

> Wanton'd as in her prime, and play'd at will
> Her virgin fancies,

it would have been readily admitted that these, or a much greater variety of substances, had been sublimed in the crevices of lava, just as several new earthy and metallic compounds are known to have been produced by fumeroles, since the eruption of 1822.

At the fortress near Torre del Greco a section is exposed, fifteen feet in height, of a current which ran into the sea; and it evinces, especially in the lower part, a decided tendency to divide into rude columns.

Mr. Scrope mentions that, in the cliffs encircling the modern crater of Vesuvius, he saw many currents offering a columnar division, and some almost as regularly prismatic as any ranges of the older basalts; and he adds, that in some the spheroidal concretionary structure, on a large scale, was equally conspicuous. Brieslak also informs us that, in the siliceous lava of 1737, which contains augite, leucite, and crystals of felspar, he found very regular prisms in a quarry near Torre del Greco; an observation confirmed by modern authorities.

Hypothesis of elevation craters not applicable to Monte Somma or to Vesuvius.—It has been imagined by MM. Von Buch and Dufrénoy, that a large part of the tufaceous strata which rise in Somma to more than half the height of the mountain are of submarine origin, an opinion which I shall show to be quite untenable. The same writers, as well as M. E. de Beaumont, have also taught that, the sheets of lava which we see in the great section of Somma laid open in the Atrio, could not originally have been inclined at angles of more than four or five degrees, so that four-fifths of their present slope must be due to their having been subsequently heaved up and tilted. Their original approach to horizontality was inferred from the compact structure of many of the beds, as well as their supposed parallelism and continuity in the line of their strike. M. E. de Beaumont, in particular, has contended that if they had run down a greater inclination than four degrees, and still more decidedly if they had pour down a slope exceeding twenty degrees, they would have consisted not of broad sheets of solid rock, but of narrow streams of porous lava and scoriæ.

I should have been at a loss to account for the support which the theoretical views above stated have received from men of such eminence, had I not been assured by my scientific friends at Naples that no one of those geologists ever visited the numerous ravines which intersect the north side of Monte Somma. In exploring these deep and narrow valleys I had the good fortune to be accompanied by Signor Guiscardi, than whom no one possesses a more thorough knowledge of the structure and composition both of Vesuvius and Monte Somma. On looking at the latter mountain from the north, I was struck with its general resemblance to old volcanic cones such as I have seen in the Canary Islands (Palma, for example), or such as Junghuhn has described in Java. From the crest of the great escarpment of the 'Atrio,' or what the Spaniards would call the 'Caldera,' deep ravines or 'barrancos,' very near each other radiate outwards in all directions, towards the north-west, north, and north-east, very shallow near the summit, but becoming rapidly deeper and having precipitous sides towards their terminations, as near the towns or villages of Santa Anastasia, Somma, and Ottajano. At the upper end of the ravine-like portion of several of these valleys is frequently seen a precipice over which a cascade falls in the rainy season when the channel of the torrent above is full of water. Passing upwards from St. Anastasia into the valley called the Casa dell' Acqua, I saw at the head of that ravine a perpendicular cliff, which is the site of one of these waterfalls, which was dry at the time. The cliff was 60 feet in height, and consisted of thin beds of stony lava interstratified with others which were more scoriaceous, and some of which were formed of loose pieces of scoriæ. At the head of an adjoining ravine called the Fosso di Cancheroni, is a much finer precipice, between 200 and 300 feet high, over which the water is thrown after heavy rains. It exhibits a great succession of beds of lava, some of them of a red colour, and much like the modern streams from Vesuvius, divided by strata of scoriæ, tuff, and breccia, the latter containing fragments of lava often leucitic, sometimes angular, and sometimes rounded by attrition. These last imply that there were gullies of aqueous erosion on the ancient flanks of Somma.

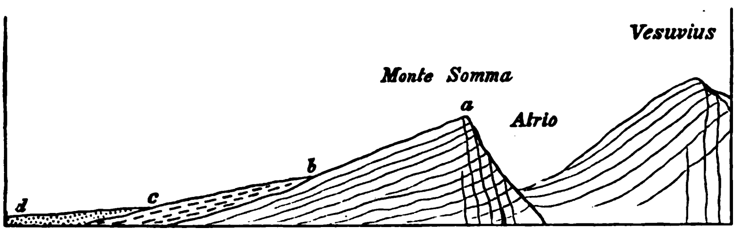
The ravine-like character of these 'barrancos' is due, I conceive, to their having been excavated by torrents cutting their way backwards. In a neighbouring valley, namely, that of Olivelli, are seen trachytic lavas with pumiceous tuffs like those which cover Pompeii, but of much older date. Blocks of white dolomite, sometimes more than a foot in diameter, occur, though rarely in the ancient tuffs, as well as blocks of lava four or five feet in diameter. Above the village of Somma we examined the parallel and adjoining ravines called the Vallone di Panico and the Vallone di Castello. Although they are very near each other, the dissimilarity of the sections which they present to the geologist is very marked. It is the same everywhere, the greatest diversity of character prevailing in the details of structure instead of that uniformity, for explaining which the theory of upheaval or elevation craters was invented. Thus, on the right side of the ravine called the Casa dell' Acqua is seen a pink lava more than 30 feet thick, containing crystals of augite and leucite, and inclined at an angle of 20 degrees, to which there is nothing answering in the next closely adjoining valleys to the east and west. The same dense mass terminates abruptly at its lower end. Some of the lavas and tuffs in the same ravine are unconformable to other sets, and must have flowed down after valleys had been excavated in the flanks of the old cone. The entire absence of dikes in most of the valleys, even in those upper parts of them which are only separated by a distance of a few hundred yards from the section in the Atrio where the dikes are so abundant, would have surprised me had I not been familiar with the same phenomenon in other volcanic mountains, especially the Canaries, where the dikes are almost entirely confined to the vicinity of the grand centres of eruption.

The annexed section (fig. 74) may give some idea of the general character of the north of Somma, so far as it is possible to represent in one view the structure of a cone, the separate parts of which are so unlike each other. The dikes so conspicuous in the Atrio terminate soon after the crest *a*; from *a* to *b* a great thickness of stony and scoriaceous lava, dipping at angles of about 20 degrees, is most conspicuous;

and from *b* to *c* white pumiceous tuffs abound, some beds having a steep, others a very slight dip, while towards the plain at *d* modern tufaceous alluvium is spread over the surface.

In no one of the tuffs in these sections have any marine shells been found; but, what is still more decisive of the sub-aerial origin of the whole mass, is the frequent occurrence of the leaves of ferns and of dicotyledonous shrubs and trees. These have been found in the valleys above St. Sebastian as well as above St. Anastasia and Ottajano—in a word, along the whole range of the flanks of the mountain, from east to west. Sometimes trunks of trees and carbonised wood occur in the tuffs at heights of 1,000 and 2,000 feet above the

Fig. 74.



Section of the north side of Monte Somma and Vesuvius.

sea, as in the valley of the Casa dell' Acqua. Leaves of the oak are not uncommon, but those of the butcher's broom, *Ruscus aculeatus*, are by far the most frequent. I believe that a rich terrestrial flora will one day be obtained from these tuffs.

Fossil sea-shells have been found in ejected fragments of sandstone and tuff in the older parts of Vesuvius on the side of Naples at the height of 972 feet above the sea; especially at a place near the Fosso Grande called the Rivo di Quaglia, which I visited with Signor Guiscardi. That gentleman has published an account of about a hundred species of marine shells, all of them save one, *Buccinum semistriatum*, of species now living in the Mediterranean, which he has obtained from fragments of tuff and sandstone cast up into the air at some

remote period and then imbedded in the old tuffs like pieces of dolomite and other rocks foreign to the mountain. They only prove that some of the early eruptions burst through tuffs of marine origin like those found between Naples and Vesuvius. Such tuffs contain similar shells, but seem only to rise to the height of about thirty feet above the level of the sea.

As to the sea-shells said to have been found on the north side of Somma, I learned that the guides, finding such fossils to be in request, have been in the habit of taking from the sea-shore fragments of tuff covered with the recent Vermetus and passing them off as fossils belonging to ancient and highly elevated beds on the flanks of Somma.

There is nothing in the dimensions of Somma which is opposed to the notion of its having originated from the same central axis of eruption as that by which the modern Vesuvius has been formed. I observed in 1857 that the top of the escarpment where it lowers towards Ottajano, as well as the flank of the old mountain below, was almost entirely devoid of vegetation, from the sterilising effect of the volcanic sand and lapilli which fell upon it during the eruption of 1822, and which were more than a foot thick at this great distance from the crater. I found in them some of those pear-shaped masses of scoriæ called volcanic bombs, also projected from the crater in 1822. This circumstance, together with the fact that the opposite side of Vesuvius was in like manner reached at an equal distance from the present centre of eruption by the matter then ejected, is a clear proof that we want no greater power than that possessed by the existing volcanos to reconstruct a cone having as large a diameter as Somma. No upheaval is wanted to perform such a feat, the ordinary forces of the elastic vapours being amply sufficient to form such a cone by ejected matter only.

The ravines then on the north side of Somma demonstrate that the origin of that mountain was due to successive flows of lava and showers of scoriæ, and that there were many long intervals of rest between successive eruptions, during which valleys of aqueous erosion were scooped out, and forest-trees and shrubs had time to grow. These plants were sometimes buried in showers of pumiceous matter, or

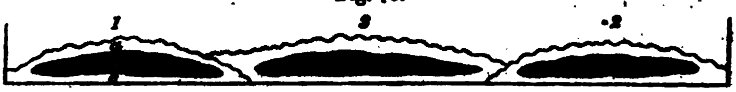
in mud sweeping down the steep slopes. But how, it will be asked, can we reconcile with all these appearances the structure of the mountain at a short distance from the ravines above described, such as is revealed to us in the grand section of the Atrio? In reply to this question, I may remark that there is no difficulty when once a close inspection is made of the arrangement and composition of those beds which are intersected by numerous dikes in the great escarpment alluded to. They are as irregular as the modern lava-streams and showers of ashes which in the years 1855 and 1857 descended slopes of between 18 and 30 degrees, and formed new envelopes of the cone arranged one above the other.

In that part of the precipice exposed in the Atrio which is called Canale del Inferno, flows of lava may be seen 12 feet thick, and consisting exclusively of fragmentary scoriæ. In many other cases the only part composed of solid rock is no more than one or two feet thick, above and below which the mass is scoriaceous and fragmentary. Not a few of these lavas may originally have formed narrow stripes on the steep slope of the ancient Somma, like those narrow bands which I saw formed by the lavas of 1855–57 and 1858, and some of which I watched descending rapidly in 1857 down the modern cone. But the enquiry will still be made, how is it possible that those continuous and horizontal sheets of stony lava, the edges of which every observer recognises in the escarpment of Somma, could have been formed by narrow rills of fluid matter descending a slope of 20 degrees? The simple answer is, that there are no such extensive stony beds. Signor Guiscardi and I convinced ourselves, in 1858, that the supposed existence of them is a delusion. There are some beds of whitish tuff, one in particular, which is very conspicuous, which the eye traces for a great length, in the middle of the great section, and which, seen at the distance, have the character of stony layers. They may have been produced simultaneously throughout their whole extent in the same manner as some layers of scoriæ of modern date, which have been seen to fall red-hot from the air, and to cover the wide expanse of the mountain-side with a mantle of fire. But when real sheets of stony lava are examined, they are never seen to reach far in a

horizontal direction, but thin out, and pass laterally into scoriæ.

I measured carefully the dimensions of one of the numerous streams of 1857, and found it to be 50 feet wide, and inclined, like the surface of the cone on which it rested, at angles varying from 18 to 28 degrees. Its average thickness was 10 feet. Having had opportunities of studying several fine cross-sections of the modern lavas of Mount Etna, which had consolidated on still steeper slopes,* I feel sure that a section of the stream in question would be such as is represented at No. 1, fig. 75, in which the central mass *b* would

Fig. 75.



Structure of successive juxtaposed modern lava-streams.

be as compact and stony as the ordinary lava of Somma, while *a* and *c* would consist of scoriaceous materials. The lower layer of scoriæ *c* is usually the least thick; it is formed in part by the sudden cooling of the lava pouring over the cold and damp soil, while the upper bed *a* is that which consolidates by contact with air. But as the mass *a b c* would rest on an old lava, the layer *c* would join on to the upper scoriæ of a subjacent stream, so that the solid and stony mass *b* would be separated by a bed of considerable thickness from the solid layer next below. The stream No. 2 next flows down and has a similar structure, and to this succeeds the third stream, No. 3, which fills up the interspace between Nos. 1 and 2, and is also made up in like manner of three parts; a cross-section of the whole exhibiting a central, almost continuous stony layer of precisely homogeneous rock, because all of the lavas proceed from one caldron of fluid matter, like those thirty or more currents which issued from the crater in 1857. Probably the beds of Monte Somma seen in the Atrio at the bottom of the great section were formed originally near the base of the cone, which had only then attained a small part of its present dimensions, and the

* See paper by the author on the Structure of Etna, Phil. Trans. 1858, p. 734.

inclination there being less than 18 degrees, some currents may have been wider than those which I saw in 1857, shooting down slopes of 30 degrees.

In the escarpment of the Atrio, the stony lavas form no more than a seventh part of the whole mass, the rest consisting of tuff or volcanic sand and fragmentary scoriæ. I observed at many points ropy lavas in this section, and some grottos which indicate tunnels like those in which modern lavas often flow (see above, p. 627). For a short distance, some stony layers in the Atrio have so steep a dip as to resemble dikes; but I doubt whether even these have been tilted, for some of the lava of 1857, on the N.N.E. side of the cone near the summit, flowed down a steep slope, reaching at one point an angle of 43 degrees. I observed that its surface was ropy and root-like, and had evidently consisted of very viscous lava. It formed what was called the 'gibbosity' of 1857, and I have no doubt that it contained within it a stony layer having a dip of at least 40 degrees. Such gibbosities are caused by the abrupt termination of viscous streams, which stop at different heights on the flanks of the cone for want of a sufficient supply of melted matter to enable them to proceed farther.

Mass enveloping Herculaneum and Pompeii.—I have spoken in the description of fig. 74, of the alluvial matter which covers the plain *c*, *d*, at the foot of the mountain. Aqueous vapours are evolved copiously from volcanic craters during eruptions, and often for a long time subsequently to the discharge of scoriæ and lava: these vapours are condensed in the cold atmosphere surrounding the high volcanic peak, and heavy rains are thus caused. The floods thus occasioned sweep along the impalpable dust and light scoriæ, till a current of mud is produced, which is called in Campania 'lava d' acqua,' and is often more dreaded than an igneous stream (lava di fuoco), from the greater velocity with which it moves. On the 27th of October, 1822, one of these alluviums descended the cone of Vesuvius, and, after overspreading much cultivated soil, flowed suddenly into the villages of St. Sebastian and Massa, where, filling the streets and interior of some of the houses, it suffocated seven persons. It will,

therefore, happen very frequently that, towards the base of a volcanic cone, alternations will be found of lava, alluvium, and showers of ashes. The great eruption, in 1822, caused a covering only a few inches thick on Pompeii. Several feet are mentioned by Prof. J. D. Forbes,* but he must have measured in spots where it had drifted. The dust and ashes were five feet thick at the top of the crater, and decreased gradually to ten inches at Torre dell' Annunziata. The size and weight of the ejected fragments diminished very regularly in the same continuous stratum, as the distance from the centre of projection was greater.

To which of these two latter divisions the mass enveloping Herculaneum and Pompeii should be referred, has been a question of the keenest controversy; but the discussion might have been shortened, if the combatants had reflected that, whether volcanic sand and ashes were conveyed to the towns by running water, or through the air, during an eruption, the interior of buildings, so long as the roofs remain entire, together with all underground vaults and cellars, could be filled only by an *alluvium*. We learn from history, that a heavy shower of sand, pumice, and lapilli, sufficiently great to render Pompeii and Herculaneum uninhabitable, fell for eight successive days and nights in the year 79, accompanied by violent rains. We ought, therefore, to find a very close resemblance between the strata covering these towns and those composing the minor cones of the Phlegræan Fields, accumulated rapidly, like Monte Nuovo, during a continued shower of ejected matter; with this difference, however, that the strata incumbent on the cities would be horizontal, whereas those on the cones are highly inclined; and that large angular fragments of rock, which are thrown out near the vent, would be wanting at a distance where small lapilli only can be found. Accordingly, with these exceptions, no identity can be more perfect than the form and distribution of the matter at the base of Monte Nuovo, as laid open by the encroaching sea, and the appearance of the beds superimposed on Pompeii. That city is covered with numerous alternations of different horizontal beds of tuff and

* Ed. Journ. of Science, No. xix. p. 131. Jan. 1829

lapilli, for the most part thin, and subdivided into very fine layers. I observed the following section near the amphitheatre, in November 1828—(descending series):—

	Feet.	Inches.
1. Black sparkling sand from the eruption of 1822, containing minute regularly formed crystals of augite and tourmaline	0	2½
2. Vegetable mould	3	0
3. Brown incoherent tuff, full of *pisolitic globules*, divided into layers, from half an inch to three inches in thickness .	1	6
4. Small scoriæ and white lapilli	0	3
5. Brown earthy tuff, with numerous pisolitic globules .	0	9
6. Brown earthy tuff, with lapilli divided into layers . .	4	0
7. Layer of whitish lapilli	0	1
8. Grey solid tuff	0	3
9. Pumice and white lapilli	0	3
	10	3½

Many of the ashes in these beds are vitrified, and harsh to the touch. Crystals of leucite, both fresh and farinaceous, have been found intermixed.* The depth of the bed of ashes above the houses is variable, but seldom exceeds 12 or 14 feet, and it is said that the higher part of the amphitheatre always projected above the surface; though if this were the case, it seems inexplicable that the city should never have been discovered till the year 1750. It will be observed in the above section, that two of the brown, half-consolidated tuffs are filled with small pisolitic globules. This circumstance is not alluded to in the animated controversy which the Royal Academy of Naples maintained with one of their members, Signor Lippi, as to the origin of the strata incumbent on Pompeii. The mode of aggregation of these globules has been fully explained by Mr. Scrope, who saw them formed in great numbers in 1822, by rain falling during the eruption on fine volcanic sand, and sometimes also produced like hail in the air, by the mutual attraction of the minutest particles of fine damp sand. Their occurrence, therefore, agrees remarkably well with the account of heavy rain, and showers of sand and ashes, recorded in history.†

* Forbes, Ed. Journ. of Science, No. xix. p. 130.

† Scrope, Geol. Trans., second series, vol. ii. p. 346.

Lippi entitled his work, 'Fù il fuoco o l'acqua che sotterò Pompei ed Ercolano?'* and he contended that the two cities were neither destroyed in the year 79, nor by a volcanic eruption, but purely by the agency of water charged with transported matter. His letters wherein he endeavoured to dispense, as far as possible, with igneous agency, even at the foot of the volcano, were dedicated, with great propriety, to Werner, and afford an amusing illustration of the polemic style in which geological writers of that day indulged themselves. His arguments were partly of an historical nature, derived from the silence of contemporary historians, respecting the fate of the cities, and partly drawn from physical proofs. He pointed out with great clearness the resemblance of the tufaceous matter in the vaults and cellars at Herculaneum and Pompeii to aqueous alluviums, and its distinctness from ejections which had fallen through the air. Nothing, he observes, but moist pasty matter could have received the impression of a woman's breast, which was found in a vault at Pompeii, or have given the cast of a statue discovered in the theatre at Herculaneum. It was objected to him, that the heat of the tuff in Herculaneum and Pompeii was proved by the carbonization of the timber, corn, papyrus-rolls, and other vegetable substances there discovered: but Lippi replied with truth, that the papyri would have been burnt up, if they had come in contact with fire, and that their being only carbonised was a clear demonstration of their having been enveloped, like fossil-wood, in a sediment deposited from water. The Academicians, in their report on his pamphlet, assert, that when the amphitheatre was first cleared out, the matter was arranged on the steps in a succession of concave layers, accommodating themselves to the interior form of the building, just as snow would lie if it had fallen there. This observation is highly interesting, and points to the difference between the stratification of ashes in an open building and of mud derived from the same in the interior of edifices and cellars. Nor ought we to call the allegation in question, because it could not be substantiated at the time of the controversy after the matter had been all

* Napoli, 1816.

removed; although Lippi took advantage of this removal, and met the arguments of his antagonists by requiring them to prove the fact. No stream of lava has ever reached Pompeii since it was first built, although the foundations of the town stand upon the old leucitic lava of Somma; several streams of which, with tuff interposed, had been cut through in excavations.

Infusorial beds covering Pompeii.—A most singular and unexpected discovery was made, in 1844–45, by Professor Ehrenberg respecting the nature of many of the layers of ashes and pumice enveloping Pompeii. He ascertained that they were, in great part, of organic and freshwater origin, consisting of the siliceous cases of microscopic infusoria. What is still more surprising, this fact proves to be by no means an isolated or solitary example of an intimate relation between organic life and the results of volcanic activity. On the Rhine, several beds of tuff and pumiceous conglomerate, resembling the mass incumbent upon Pompeii and closely connected with extinct volcanos, are now ascertained to be made up to a great extent of the siliceous cases of infusoria (or rather Diatomaceæ), invisible to the naked eye and often half fused.* No less than 94 distinct species have already been detected in one mass of this kind, more than 150 feet thick, at Hochsimmer, on the left bank of the Rhine, near the Laacher-see. Some of these Rhenish infusorial accumulations appear to have fallen in showers, others to have been poured out of lake-craters in the form of mud, as in the Brohl valley.

In Mexico, Peru, the Isle of France, and several other volcanic regions, analogous phenomena have been observed, and everywhere the species of infusoria belong to freshwater and terrestrial genera, except in the case of the Patagonian pumiceous tuffs, specimens of which, brought home by Mr. Darwin, are found to contain the remains of marine animalcules. In various kinds of pumice ejected by volcanos, the microscope has revealed to Professor Ehrenberg the siliceous

* Not a few of the organic bodies, called by Ehrenberg 'infusoria,' such as Gaillonella and Bacillaria, once supposed to belong to the animal kingdom, are now regarded by botanists as plants, and are called Diatomaceæ and Desmidiæ.

cases of infusoria often half obliterated by the action of heat, and the fine dust thrown out into the air during eruptions is sometimes referable to these most minute organic substances brought up from considerable depths, and sometimes mingled with small particles of vegetable matter.

In what manner did the solid coverings of these most minute plants and animalcules, which can only originate and increase at the surface of the earth, sink down and penetrate into subterranean cavities, so as to be ejected from the volcanic orifices? We have of late years become familiar with the fact in the process of boring Artesian wells, that the seeds of plants, the remains of insects, and even small fish, with other organic bodies, are carried in an uninjured state by the underground circulation of waters, to the depth of many hundred feet. With still greater facility in a volcanic region we may conjecture, that water and mud full of invisible infusoria may be sucked down, from time to time, into subterranean rents and hollows in cavernous lava which has been permeated by gases, or in rocks dislocated by earthquakes. It often happens that a lake which has endured for centuries in a volcanic crater, disappears suddenly on the approach of a new eruption. Violent shocks agitate the surrounding region, and ponds, rivers, and wells are dried up. Large cavities far below may thus become filled with fen-mud chiefly composed of the more indestructible and siliceous portions of infusoria, destined perhaps to be one day ejected in a fragmentary or half-fused state, yet without the obliteration of all traces of organic structure.*

Herculaneum.—It was remarked that no lava has flowed

* See Ehrenberg, Proceedings (Berichte) of the Royal Acad. of Sci. Berlin, 1844, 1845, and an excellent abstract of his papers by Mr. Ansted in the Quart. Journ. of the Geol. Soc. London, No. 7. Aug. 1846. In regard to marine infusoria found in volcanic tuff, it is well known that on the shores of the island of Cephalonia in the Mediterranean (Proceedings, Geol. Soc. vol. ii. p. 220) there is a cavity in the rock, into which the sea has been flowing for ages, and many others doubtless exist in the leaky bottom of the ocean. The marine current has been rushing in for many years, and as the infusoria inhabiting the waters of the Mediterranean are exceedingly abundant, a vast store of their cases may accumulate in submarine caverns (the water, perhaps, being converted into steam, and so escaping upwards), and they may then be cast up again to furnish the materials of volcanic tuff, should an eruption occur like that which produced Graham Island, off the coast of Sicily, in 1831.

over the site of Pompeii, since that city was built, but with Herculaneum the case is different. Although the substance which fills the interior of the houses and the vaults in that buried city must have been introduced in a state of mud, like that found in similar situations in Pompeii; yet the superincumbent mass differs wholly in composition and thickness. Herculaneum was situated several miles nearer to the volcano, and has, therefore, been always more exposed to be covered, not only by showers of ashes, but by alluviums and streams of lava. Accordingly, masses of both have accumulated on each other above the city, to a depth of nowhere less than 70, and in many places of 112 feet.*

The tuff which envelopes the buildings consists of comminuted volcanic ashes, mixed with pumice. A mask embedded in this matrix has left a cast, the sharpness of which was compared by Hamilton to those in plaster of Paris; nor was the mask in the least degree scorched, as if it had been imbedded in heated matter. This tuff is porous; and, when first excavated, is soft and easily worked, but acquires a considerable degree of induration on exposure to the air. Above this lowest stratum is placed, according to Hamilton, 'the matter of six eruptions,' each separated from the other by veins of good soil. In these soils Lippi states that he collected a considerable number of land shells—an observation which is no doubt correct; for many snails burrow in soft soils, and some Italian species descend, when they hybernate, to the depth of five feet and more from the surface. Della Torre also informs us that there is in one part of this superimposed mass a bed of true siliceous lava (*lava di pietra dura*); and, as no such current is believed to have flowed till near 1,000 years after the destruction of Herculaneum, we must conclude that the origin of a large part of the covering of Herculaneum was long subsequent to the first inhumation of the place. That city, as well as Pompeii, was a seaport. Herculaneum is still very near the shore, but a tract of land, a mile in length, intervenes between the borders of the Bay of Naples and Pompeii. In both cases the gain of land is due to the filling up of the bed of the sea with volcanic

* Hamilton, Observ. on Mount Vesuvius, p. 94. London, 1774.

matter, and not to elevation by earthquakes, for there has been no change in the relative level of land and sea. Pompeii stood on a slight eminence composed of the lavas of the ancient Vesuvius, and flights of steps led down to the water's edge. The lowermost of these steps are said to be still on an exact level with the sea.

Conditions and contents of the buried cities.—After these observations on the nature of the strata enveloping and surrounding the cities, we may proceed to consider their internal condition and contents, so far at least as they offer facts of geological interest. Notwithstanding the much greater depth at which Herculaneum was buried, it was discovered before Pompeii, by the accidental circumstance of a well being sunk, in 1713, which came right down upon the theatre, where the statues of Hercules and Cleopatra were soon found. Whether this city or Pompeii, both of them founded by Greek colonies, was the more considerable, is not yet determined; but both are mentioned by ancient authors as among the seven most flourishing cities in Campania. The walls of Pompeii were three miles in circumference; but we have, as yet, no certain knowledge of the dimensions of Herculaneum. In the latter place the theatre alone is open for inspection; the Forum, Temple of Jupiter, and other buildings, having been filled up with rubbish as the workmen proceeded, owing to the difficulty of removing it from so great a depth below ground. Even the theatre is only seen by torchlight, and the most interesting information, perhaps, which the geologist obtains there, is the continual formation of stalactite in the galleries cut through the tuff; for there is a constant percolation of water charged with carbonate of lime mixed with a small portion of magnesia. Such mineral waters must, in the course of time, create great changes in many rocks; especially in lavas, the pores of which they may fill with calcareous spar, so as to convert them into amygdaloids. Some geologists, therefore, are unreasonable when they expect that volcanic rocks of remote eras should accord precisely with those of modern date; since it is obvious that many of those produced in our own time will not long retain the same aspect and internal composition

Both at Herculaneum and Pompeii, temples have been found with inscriptions commemorating the rebuilding of the edifices after they had been thrown down by an earthquake.* This earthquake happened in the reign of Nero, sixteen years before the cities were overwhelmed. In Pompeii, one fourth of which is now laid open to the day, both the public and private buildings bear testimony to the catastrophe. The walls are rent, and in many places traversed by fissures still open. Columns are lying on the ground only half hewn from huge blocks of travertin, and the temple for which they were designed is seen half repaired. In some few places the pavement had sunk in, but in general it was undisturbed, consisting of large irregular flags of lava joined neatly together, in which the carriage wheels have often worn ruts an inch and a half deep. In the wider streets, the ruts are numerous and irregular; in the narrower there are only two, one on each side, which are very conspicuous. It is impossible not to look with some interest even on these ruts, which were worn by chariot wheels more than seventeen centuries ago; and, independently of their antiquity, it is remarkable to see such deep incisions so continuous in a stone of great hardness.

Small number of skeletons.—A very small number of skeletons have been discovered in either city; and it is clear that most of the inhabitants not only found time to escape, but also to carry with them the principal part of their valuable effects. In the barracks of Pompeii were the skeletons of two soldiers chained to the stocks, and in the vaults of a country-house in the suburbs were the skeletons of seventeen persons, who appear to have fled there to escape from the shower of ashes. They were found enclosed in an indurated tuff, and in this matrix was preserved a perfect cast of a woman, perhaps the mistress of the house, with an infant in her arms. Although her form was imprinted on the rock, nothing but the bones remained. To these a chain of gold was suspended, and on the fingers of the skeletons were rings with jewels. Against the sides of the same vault was ranged a long line of earthen amphoræ.

* Swinburne and Lalande. Paderni, Phil. Trans. 1758, vol. i. p. 619.

The writings scribbled by the soldiers on the walls of their barracks, and the names of the owners of each house written over the doors, are still perfectly legible. The colours of fresco paintings on the stuccoed walls in the interior of buildings are almost as vivid as if they were just finished. There are public fountains decorated with shells laid out in patterns in the same fashion as those now seen in the town of Naples; and in the room of a painter, who was perhaps a naturalist, a large collection of shells was found, comprising a great variety of Mediterranean species, in as good a state of preservation as if they had remained for the same number of years in a museum. A comparison of these remains with those found so generally in a fossil state would not assist us in obtaining the least insight into the time required to produce a certain degree of decomposition or mineralisation; for, although under favourable circumstances much greater alteration might doubtless have been brought about in a shorter period, yet the example before us shows that an inhumation of seventeen centuries may sometimes effect nothing towards the reduction of shells to the state in which fossils are usually found.

The wooden beams in the houses at Herculaneum are black on the exterior, but, when cleft open, they appear to be almost in the state of ordinary wood, and the progress made by the whole mass towards the state of lignite is scarcely appreciable. Some animal and vegetable substances of more perishable kinds have of course suffered much change and decay, yet the state of preservation of these is truly remarkable. Fishing-nets are very abundant in both cities, often quite entire; and their number at Pompeii is the more interesting from the sea being now, as we stated, a mile distant. Linen has been found at Herculaneum, with the texture well defined; and in a fruiterer's shop in that city were discovered vessels full of almonds, chesnuts, walnuts, and fruit of the 'carubiere,' all distinctly recognisable from their shape. A loaf, also, still retaining its form, was found in a baker's shop, with his name stamped upon it. On the counter of an apothecary was a box of pills converted into a fine earthy substance; and by the side of it a small cylindrical roll

evidently prepared to be cut into pills. By the side of these was a jar containing medicinal herbs. In 1827, moist olives were found in a square glass-case, and 'caviare,' or roe of a fish, in a state of wonderful preservation. An examination of these curious condiments has been published by Covelli of Naples, and they are preserved hermetically sealed in the museum there.*

Papyri.—There is a marked difference in the condition and appearance of the animal and vegetable substances found at Pompeii and Herculaneum; those of Pompeii being penetrated by a grey pulverulent tuff, those in Herculaneum seeming to have been first enveloped by a paste which consolidated round them, and then allowed them to become slowly carbonised. Some of the rolls of papyrus at Pompeii still retain their form; but the writing, and indeed almost all the vegetable matter, appear to have vanished, and to have been replaced by volcanic tuff somewhat pulverulent. At Herculaneum the earthy matter has scarcely ever penetrated; and the vegetable substance of the papyrus has become a thin friable black matter, almost resembling in appearance the tinder which remains when stiff paper has been burnt, in which the letters may still be sometimes traced. The small bundles of papyri, composed of five or six rolls tied up together, had sometimes lain horizontally, and were pressed in that direction, but sometimes they had been placed in a vertical position. Small tickets were attached to each bundle, on which the title of the work was inscribed. In one case only have the sheets been found with writing on both sides of the pages. So numerous are the obliterations and corrections, that many must have been original manuscripts. The variety of handwritings is quite extraordinary: nearly all are written in Greek, but there are a few in Latin. They were almost all found in a suburban villa in the library of one private individual; and the titles of four hundred of those least injured, which have been read, are found to be unimportant works, but all entirely new, chiefly relating to music, rhetoric, and cookery. There are two volumes of Epicurus 'On Nature,' and the others are mostly by writers of the same school, only

* Prof. J. D. Forbes, Edin. Journ. of Sci., No. xix. p. 130. Jan. 1829.

one fragment having been discovered, by an opponent of the Epicurean system, Chrysippus. In one of the manuscripts which was in the hands of the interpreters when I visited the museum in 1828, the author indulges in the speculation that all the Homeric personages were allegorical—that Agamemnon was the ether, Achilles the sun, Helen the earth, Paris the air, Hector the moon, &c. If the opinion of some antiquaries be correct that not one hundredth part of Herculaneum has yet been explored, we may still hope that some rolls of papyrus may yet be found containing some of the lost works of the Augustan age, or of eminent Greek historians and philosophers.

Stabiæ.—Besides the cities already mentioned, Stabiæ, a small town about six miles from Vesuvius, and near the site of the modern Castel-a-Mare (see map of volcanic district of Naples, p. 600), was overwhelmed during the eruption of 79. Pliny mentions that, when his uncle was there, he was obliged to make his escape, so great was the quantity of falling stones and ashes. In the ruins of this place, a few skeletons have been found buried in volcanic ejections, together with some antiquities of no great value, and rolls of papyrus, which, like those of Pompeii, were illegible.

Torre del Greco overflowed by lava.—Of the towns hitherto mentioned, Herculaneum alone has been overflowed by a stream of melted matter; but this did not, as we have seen, enter or injure the buildings, which were previously enveloped or covered over with tuff. But burning torrents have often taken their course through the streets of Torre del Greco, and consumed or enclosed a large portion of the town in solid rock. It seems probable that the destruction of three thousand of its inhabitants in 1631, which some accounts attribute to boiling water, was principally due to one of those alluvial floods which we before mentioned; but, in 1737, the lava itself flowed through the eastern side of the town, and afterwards reached the sea; and, in 1794, another current, rolling over the western side, filled the streets and houses, and killed more than four hundred persons. The main street is now quarried through this lava, which supplied building stones for new houses erected where others had been

annihilated. The church was half buried in a rocky mass, but the upper portion served as the foundation of a new edifice.

The number of the population when I was first there, in 1828, was estimated at fifteen thousand; and a satisfactory answer may readily be returned to those who enquire how the inhabitants can be so 'inattentive to the voice of time and the warnings of nature,'* as to rebuild their dwellings on a spot so often devastated. No neighbouring site unoccupied by a town, or which would not be equally insecure, combines the same advantages of proximity to the capital, to the sea, and to the rich lands on the flanks of Vesuvius. If the present population were exiled, they would immediately be replaced by another, for the same reason that the Maremma of Tuscany and the Campagna di Roma will never be depopulated, although the malaria fever commits more havoc in a few years than the Vesuvian lavas in as many centuries. The district around Naples supplies one amongst innumerable examples, that those regions where the surface is most frequently renewed, and where the renovation is accompanied, at different intervals of time, by partial destruction of animal and vegetable life, may nevertheless be amongst the most habitable and delightful on our globe, and the remark applies as well to parts of the surface which are the abode of aquatic animals as to those which support terrestrial species. The sloping sides of Vesuvius give nourishment to a vigorous and healthy population of about eighty thousand souls; and the surrounding hills and plains, together with several of the adjoining isles, owe the fertility of their soil to matter ejected by prior eruptions. Had the fundamental limestone of the Apennines remained uncovered throughout the whole area, the country could not have sustained a twentieth part of its present inhabitants. This will be apparent to every geologist who has marked the change in the agricultural character of the soil the moment he has passed the utmost boundary of the volcanic ejections, as when, for example, at the distance of about seven miles from

* Sir H. Davy, Consolations in Travel, p. 66.

Vesuvius, he leaves the plain and ascends the declivity of the Sorrentine Hills.

Yet favoured as this region has been by Nature from time immemorial, the signs of the changes imprinted on it during the period that it has served as the habitation of man may appear in after-ages to indicate a series of unparalleled disasters. Let us suppose that at some future time the Mediterranean should form a gulf of the great ocean, and that the waves and tidal current should encroach on the shores of Campania, as it now advances upon the eastern coast of England; the geologist will then behold the towns already buried, and many more which will evidently be entombed hereafter, laid open in the steep cliffs, where he will discover buildings superimposed above each other, with thick intervening strata of tuff or lava—some unscathed by fire, like those of Herculaneum and Pompeii; others half melted down, as in Torre del Greco; and many shattered and thrown about in strange confusion, as in Tripergola, beneath Monte Nuovo. Among the ruins will be seen skeletons of men, and impressions of the human form stamped in solid rocks of tuff. Nor will the signs of earthquakes be wanting. The pavement of part of the Domitian Way, and the temple of the nymphs, submerged at high tide, will be uncovered at low water, the columns remaining erect and uninjured. Other temples which had once sunk down, like that of Serapis, will be found to have been upraised again by subsequent movements. If they who study these phenomena, and speculate on their causes, assume that there were periods when the laws of Nature or the whole course of natural events differed greatly from those observed in their own time, they will scarcely hesitate to refer the wonderful monuments in question to those primeval ages. When they consider the numerous proofs of reiterated catastrophes to which the region was subject, they may, perhaps, commiserate the unhappy fate of beings condemned to inhabit a planet during its nascent and chaotic state, and feel grateful that their favoured race has escaped such scenes of anarchy and misrule.

Yet what was the real condition of Campania during those years of dire convulsion? 'A climate,' says Forsyth, 'where

heaven's breath smells sweet and wooingly—a vigorous and luxuriant nature unparalleled in its productions—a coast which was once the fairy-land of poets, and the favourite retreat of great men. Even the tyrants of the creation loved this alluring region, spared it, adorned it, lived in it, died in it.'* The inhabitants, indeed, have enjoyed no immunity from the calamities which are the lot of mankind; but the principal evils which they have suffered must be attributed to moral, not to physical, causes—to disastrous events over which man might have exercised a control, rather than to the inevitable catastrophes which result from subterranean agency. When Spartacus encamped his army of ten thousand gladiators in the old extinct crater of Vesuvius, the volcano was more justly a subject of terror to Campania than it has ever been since the rekindling of its fires.

* Forsyth's Italy, vol. ii.

INDEX.

END OF THE FIRST VOLUME.

The Human Species.

By A. De Quatrefages, Professor of Anthropology in the Museum of Natural History, Paris. 12mo. Cloth, $2.00.

The work treats of the unity, origin, antiquity, and original localization of the human species, peopling of the globe, acclimatization, primitive man, formation of the human races, fossil human races, present human races, and the physical and psychological characters of mankind.

Students' Text-book of Color; or, Modern Chromatics.

With Applications to Art and Industry. With one hundred and thirty Original Illustrations, and Frontispiece in Colors. By Ogden N. Rood, Professor of Physics in Columbia College. 12mo. Cloth, $2.00.

"In this interesting book Professor Rood, who, as a distinguished Professor of Physics in Columbia College, United States, must be accepted as a competent authority on the branch of science of which he treats, deals briefly and succinctly with what may be termed the scientific *rationale* of his subject. But the chief value of his work is to be attributed to the fact that he is himself an accomplished artist as well as an authoritative expounder of science."—*Edinburgh Review*, *October*, 1879, *in an article on "The Philosophy of Color."*

Education as a Science.

By Alexander Bain, LL. D. 12mo. Cloth, $1.75.

"This work must be pronounced the most remarkable discussion of educational problems which has been published in our day. We do not hesitate to bespeak for it the widest circulation and the most earnest attention. It should be in the hands of every schoolteacher and friend of education throughout the land."—*New York Sun.*

A History of the Growth of the Steam-Engine.

By Robert H. Thurston, A. M., C. E., Professor of Mechanical Engineering in the Stevens Institute of Technology, Hoboken, N. J., etc. With one hundred and sixty-three Illustrations, including fifteen Portraits. 12mo. Cloth, $2.50.

"Professor Thurston almost exhausts his subject; details of mechanism are followed by interesting biographies of the more important inventors. If, as is contended, the steam-engine is the most important physical agent in civilizing the world, its history is a desideratum, and the readers of the present work will agree that it could have a no more amusing and intelligent historian than our author."—*Boston Gazette.*

Studies in Spectrum Analysis.

By J. Norman Lockyer, F. R. S., Corespondent of the Institute of France, etc. With sixty Illustrations. 12mo. Cloth, $2.50.

"The study of spectrum analysis is one fraught with a peculiar fascination, and some of the author's experiments are exceedingly picturesque in their results. They are so lucidly described, too, that the reader keeps on, from page to page, never flagging in interest in the matter before him, nor putting down the book until the last page is reached." —*New York Evening Express.*

D. APPLETON & CO., Publishers,

1, 3, & 5 Bond Street, New York.

Fol 16

Feb 10